AN INTELLIGENT MODEL OF VARIATIONS' CONTINGENCY ON CONSTRUCTION PROJECTS

BY

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DEDICATION

This work is dedicated to my mother from whom I have learnt that, with hard work and prayer, dream can become a reality.

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Abstract

This research is an explanatory and quantitative investigation of variations on construction projects in UK. Variations on construction projects are inevitable often causing a major impact on the progress of the work resulting in disruption and delay, often resulting in claims and costly litigation. However at the pre-contract stage little attention is given to establishing the appropriate contingency allowance for variations, this is probably one of the most neglected areas of construction management.

The premise of the research was that the magnitude of variations on construction projects is influenced by construction process factors. The research sought to identify those factors and to establish the relationship between the magnitude of variations and the factors. Using the established relationship, a quantitative model can be developed to predict the contingency allowance for variations.

Through a questionnaire case study approach, several factors in the construction process were found to influence the magnitude of variations. The relationship between variations and those factors form the basis for the developed artificial intelligent based neural network model developed in the research for predicting variations' contingency.

The validation test of the model shows that the model can, with an acceptable degree of accuracy, predict and justify the total cost of variations on construction projects. The

model, if used as a management tool to predict the contingencies, would not only assist in planning for variations but also facilitate negotiation of their cost and reduce the uncertainty of the project.

Acknowledgment

This research could not have been possible without the generous help and encouragement of many individuals and organisations.

First of all, I am indebted to my supervisor, Mr. Keith Potts, for assistance, encouragement and contribution throughout the course of this research. I will also like to thank Dr. Issaka Ndekugri and Professor Frank Harris for their supervision, advice and encouragement. Thank you very much.

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Finally, thanks to God almighty for his mercy and making this dream becomes a reality.

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Chapter 1

General Introduction

1.1 INTRODUCTION

Variations on construction projects and problems associated with them have over the years received attention on many occasions, especially from legal practitioners and writers on construction issues. It is a widely accepted fact in the industry that variations are inevitable and are the major causes of cost and time overruns on construction projects. Despite these observations the subject of variations has received insufficient attention from researchers.

Generally, research on variations has been limited to the identification of the nature, source and cause of variations, for example Bromilow (1970) identified the sources and nature of variations on building contracts in Australia. The work was further extended into modelling the incidence of variations and their cost and time impact on building contracts (Bromilow, 1969 & 1971; Bromilow & Henderson, 1971), with the conclusion that a project's cost was influenced by variations regardless of their time impact on the project.

Hibberd (1980), in a research conducted in the UK, categorised the sources and nature of variations in relation to the forms of contract, giving great attention to claim issues concerning variations on building contracts. He concluded that variations affect the overall time and cost performance and further create project management problems such as, delay and disruption, claims and disputes.

In another research investigation in the UK, the development and incidence of variations on building contracts were considered in relation to the interpersonal relationship between the project team members, i.e., architect/engineer, quantity surveyor, contractor's site manager/engineer, etc. (Langford, Fellows, and Newcombe, 1986) and the co-ordination and communication process of the team (McDermott and Newcombe, 1986).

Variations are generally used on construction projects to modify or add to what is initially agreed. Clients may redefine their needs which may require changes to the initial design. Also the Architect or Engineer may issue variations to benefit from newly available materials or a revised construction method indeed the decision to initiate these changes and their effects on the project performance will be influenced by many factors. For example, Bromilow (1970) identified the client and project characteristics as the influencing factors, while Langford et al (1986) and McDermott & Newcombe (1986) on the same research project identified the social system (interpersonal relationship) and the co-ordination and communication process of the team as factors influencing the development and incident of variations on construction projects.

However, the generation of variations, their timing, their negotiation and how they are valued, will also be dependent on organisational factors such as the form of contract and the contract strategy (procurement system). Unfortunately, previous studies on variations have tended to consider only the influence of the client and project characteristics with the social relationship of the team in relation to project performance in isolation from other organisational factors.

Part of the objectives of the research, therefore, is to review construction management research studies, to identify, discuss and quantify the factors that may influence the number and magnitude of variations and their effect on project performance. The term 'magnitude' of variations uses denote the cost significance of variations on construction projects.

1.2 AIMS

Invariably there will be unforeseen events that will lead to variations on any construction project. In the planning for any project the contingency allowance is generally forecast and included in the budget/estimate as a means of planning for the eventual occurrences of variations. The traditional practice is to allocate an arbitrary percentage of the project cost forecast/budget as a contingency to cover variations. The determination of this percentage is based on subjective judgement of the project management team. The inefficiency of this approach is evidenced by the continuous increases in disruption, disputes and claim on construction projects due to variations.

The broad aim of the research study therefore, is:

to develop an artificial intelligent based neural network model to assess and predict variations' contingency on construction projects as a tool for planning for variations.

1.3 OBJECTIVES

Realising the research aims would involve the following objectives:

(i) to examine existing practice for determining the contingency allowance for unforeseen events that leads to variations on construction projects.

(ii) to identify and analyse the sources, nature, and magnitude of variations on construction projects in UK construction industry.

(iii) to identify and analyse the factors influencing the sources, nature and decision to order variations on various types of construction projects in UK

(iv) to analyse and determine the relationship between the identified factors and the incidence of variations on construction projects.

(v)to model the magnitude of variations based on the analysis in (v) above, test and evaluate the validity of the model.

1.4 Methodology

As with most research, the first task of the researcher was to define the problem area and propose method of solution. Realising the broadness of the topic and the many possibilities of approach and bearing in mind that the research arose out of the need to understand further the problems associated with variations, the scope of the research, had to be limited to the issue of how variations can be properly planned for through proper contingency to contain their impact the project performance. By adopting this approach, we hope to reduce the disruptive effects of variations through effective management and control based on the tools developed.

After the literature review to establish the theoretical background to the research and proper definition of the problem, the rest of the research can be divided into five stages: informal interview and discussion with cross section of professionals

involved with construction, evaluation of information and pilot survey; main survey/interview; analysis and modelling of the findings; and testing and validation of the model.

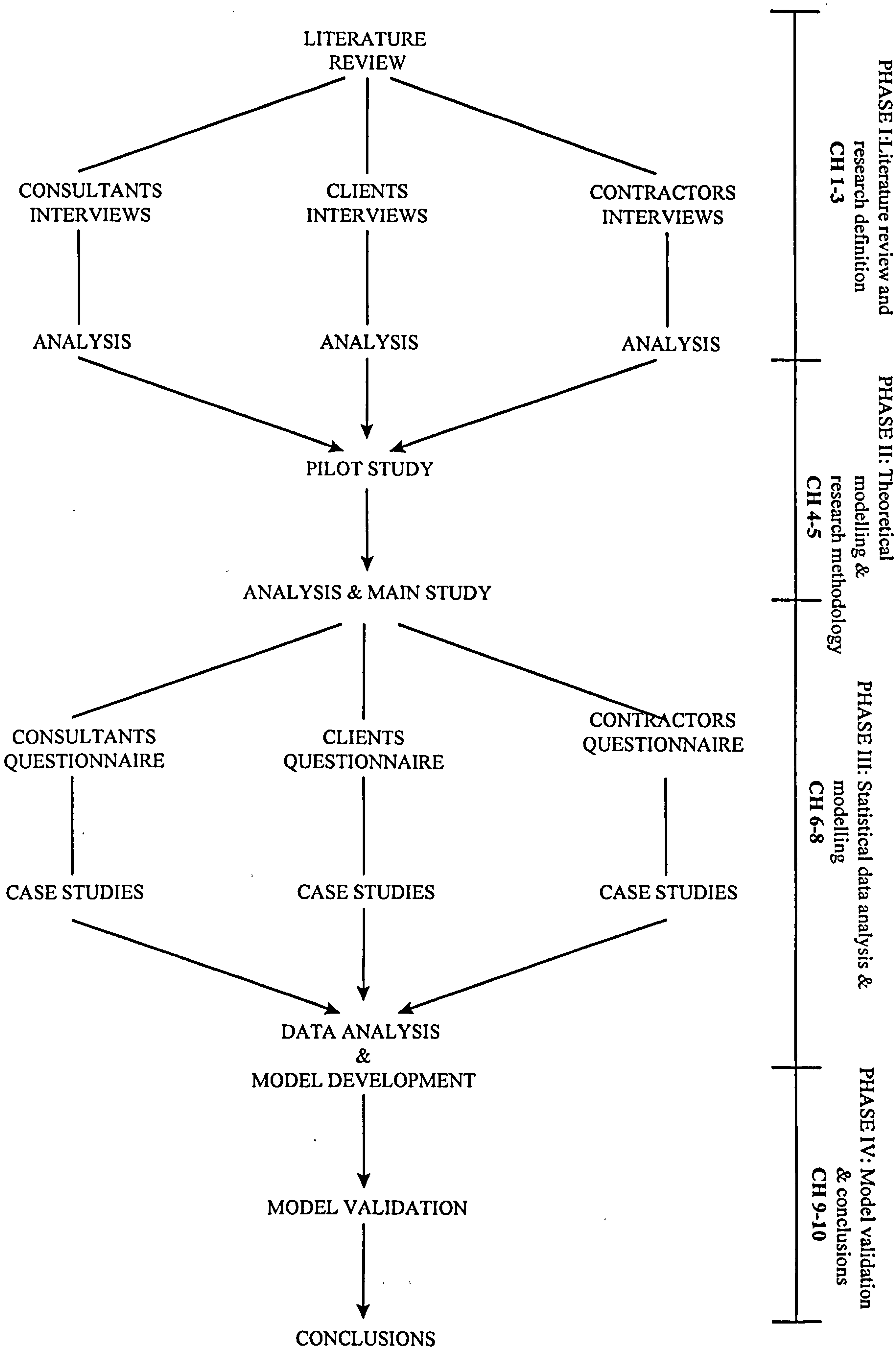


FIG. 1.1: RESEARCH METHODOLOGY

1.5 Structure of Thesis

Figure 1.1 illustrates the various steps taken in this research to achieve the stated aim and objectives. These stages are classified into four main phases which are presented as nine core chapters which are now briefly described.

Chapter 2 - The Construction Industry Production Process and Management of Risk and Uncertainty

This chapter provide an overview of the UK construction industry. It discusses the characteristic structure of the industry in relation to the issue of risk and uncertainty of construction projects and how they are managed.

Chapter 3 - The Anatomy of Variations on Construction Projects

This chapter reviews the literature on variations and relevant subject area. The review are presented in two parts; the first part reviews the source and nature of variations and their magnitude and impact on performances. The second part identifies and discusses the factors influencing variations and gives an overview of how variations as risk are managed.

Chapter 4 - Artificial Neural Networks Theoretical Development and Applications

The work in this chapter focuses on artificial neural networks as a modelling technique. The theoretical background and development of the technique within a construction scenario are reviewed highlighting other potential areas of construction management that can benefit from the ability of the technique.

Chapter 5 - The Research Methodology

This chapter gives a detailed description of the research methodology adopted in carrying out the research study. The methodology was made up of the four phases graphically illustrated in figure 1.1 above.

Chapter 6 - The Extent and Sources of Variations

The chapter discusses the research investigation findings on the extent and sources of variations on construction projects. It also discusses the evaluation of performances of variation clause(s) within the general conditions of contracts.

Chapter 7 - An Evaluation of Factors Influencing Variations

Having confirmed the extent and sources of variations on construction projects, it is important to evaluate those factors identified as influencing the decisions and magnitude of variations. The analysis of evaluation of the influencing factors are discussed in this chapter.

Chapter 8 - ARTIFICIAL NEURAL NETWORK MODEL OF VARIATIONS

Having established the relationship between variations and the various construction process factors, this chapter presents the discussion of the modelling of the established relationship in order to develop, test and compare two predictive models based on two different techniques: artificial neural network, and multiple regression.

Chapter 9 - The Validation of the Model

This chapter describes the procedure adopted for the validation of the artificial neural network model predicting the contingency amount to be allowed for variations. The results of the validation tests and the application of the model are discussed.

Chapter 10 - Conclusion and Recommendations For Future Works

Concludes the results obtained in the research and gives some fundamental use of the model as a project management tool. Area of further research works are also suggested.

CHAPTER TWO

AN OVERVIEW OF THE CONSTRUCTION INDUSTRY PRODUCTION PROCESS AND MANAGEMENT OF RISK AND UNCERTAINTY

2.1 Introduction

The research problem and need for the research, as already stated in chapter one, stem from the magnitude, frequency and problem of variations on construction projects, their performance. Generally there is a lack of qualitative or quantitative research focused on this issue. Chapter one also outlined the research aims and objectives and the strategy of the research.

In order to put the research problem into perspective and understand the explanation or excuses of the industry for the problem, this chapter provides an overview of the construction industry and a context for the research problem. The discussion focuses on the nature and characteristics of the construction industry and the unique characteristics of its products and their delivery systems with an overview of how the inherent risk and uncertainty of the construction project are managed.

2.2 The Nature of Construction Industry

The construction industry which embraces the building and civil engineering sectors including the petro-chemical and process-plant, play an important role in the British economy. It accounted for about 10% of the value of goods in 1995 and employed over 12% of the total work force (DOE (1996)). The industry contributes about half of the nation's fixed investment. The economic significance of the construction industry indicates the importance of the industry in helping the national government achieve its economic and social objectives.

The construction industry as a service industry, combines the skills of different professions and material and component manufacturers, with the effort of the builders in order to produce the constructed product (Sidwell, 1982). The industry is not only very large, it is also characteristically heterogeneous and fragmented. Those significant features and the physical nature of the industry product and production process, makes the construction industry characteristically unique in comparison with other industries (Hillebrandt, 1984).

As an important industry in the nation's economy, the construction industry for decades has been facing problems relating to organisation and management of its production process and its product performance effectiveness. Banwell (1964) identified the need for review into how the industry organised its production process. He expressed the need for flexibility of the contractual and project organisation as essential to an industry in the process of modernisation. As an explanation or excuse for the problems, many studies have attributed these problems to the unique characteristic of the industry (Hillebrandt, 1984; Hillebrandt and Cannon, 1989; Ball, 1980). Ball (1980) and Hillebrandt (1984) classifying those unique characteristics as:

(i) the economic structure of the industry,

(ii) the physical nature of its product, and

(iii) its production process.

These characteristics go a long way to explain the structure, project organisation, methods of control and decision making in the industry (Hillebrandt and Cannon, 1989). Therefore, in order to gain a proper perspective of the problems and how the industry might improve its performance, an understanding of these characteristics is desirable.

2.2.1 Structure of construction industry

The structure of the construction industry is complex and distinctive compared to other industries (Ball, 1980; Hillebrandt, 1984)). A significant feature of this structural complexity is the industry fragmentation which traditionally has separated the design and production functions, unlike the manufacturing industry where the design function is an integral part of production. As a result, the industry is dominated by a growing number of small firms and the self-employed. The majority of the firms thus are construction contracting organisations, over 100,000 in 1994. The vast majority of those firms are medium- to small-size, with about 70% of them having four or fewer employees (DOE (1996)). The large and small firms in the construction industry are frequently economically linked together on a project to project basis via, often, a chain of subcontracting.

The employment condition within the construction industry, being a labour intensive industry with high proportion of self-employed work force, do not conform to those of other manufacturing industries. A significant proportion of wages in the industry is made up of incentive payments. However, the construction industry in Britain, like most major industries in an advanced economy, is organised and structured on the basis of its production for profit (Ball, 1980).

2.2.2 The production process

The construction industry, as a result of its structural fragmentation, combines the skills of different professions and organisations in the course of its production. Construction as a process has a starting point and an end point (Gardiner, 1992). Traditionally, the construction process is viewed as a set of distinctive activities and functions carried out one after the other. A simplified model of the process is shown in Figure 2.1 (Gardiner, 1990). The figure shows in flow diagrammatic form the sequences of activities to be completed at various stages of the construction process. It starts with the client's need and decision to build, and ends with the completion of the project.

Over the years the traditional view of the construction process has been challenged and used as an excuse for the problems of performance and organisation effectiveness (Banwell, 1964; Higgin and Jessop, 1966; Crichton, 1966; Morris, 1972). Morris(1972) for example, identified the main area of difficulty in the process as the coordination and control of the design-construction interface. He saw the key priority for increasing performance and effectiveness of the construction process to lie in the management of the dynamic interrelationships between various organisations and professions involved in the process. Other problems identified included poor communication (Higgin and Jessop, 1966), uncertainty and interdependence (Crichton, 1966), and increasing project complexity (Bennett and Fine, 1980).

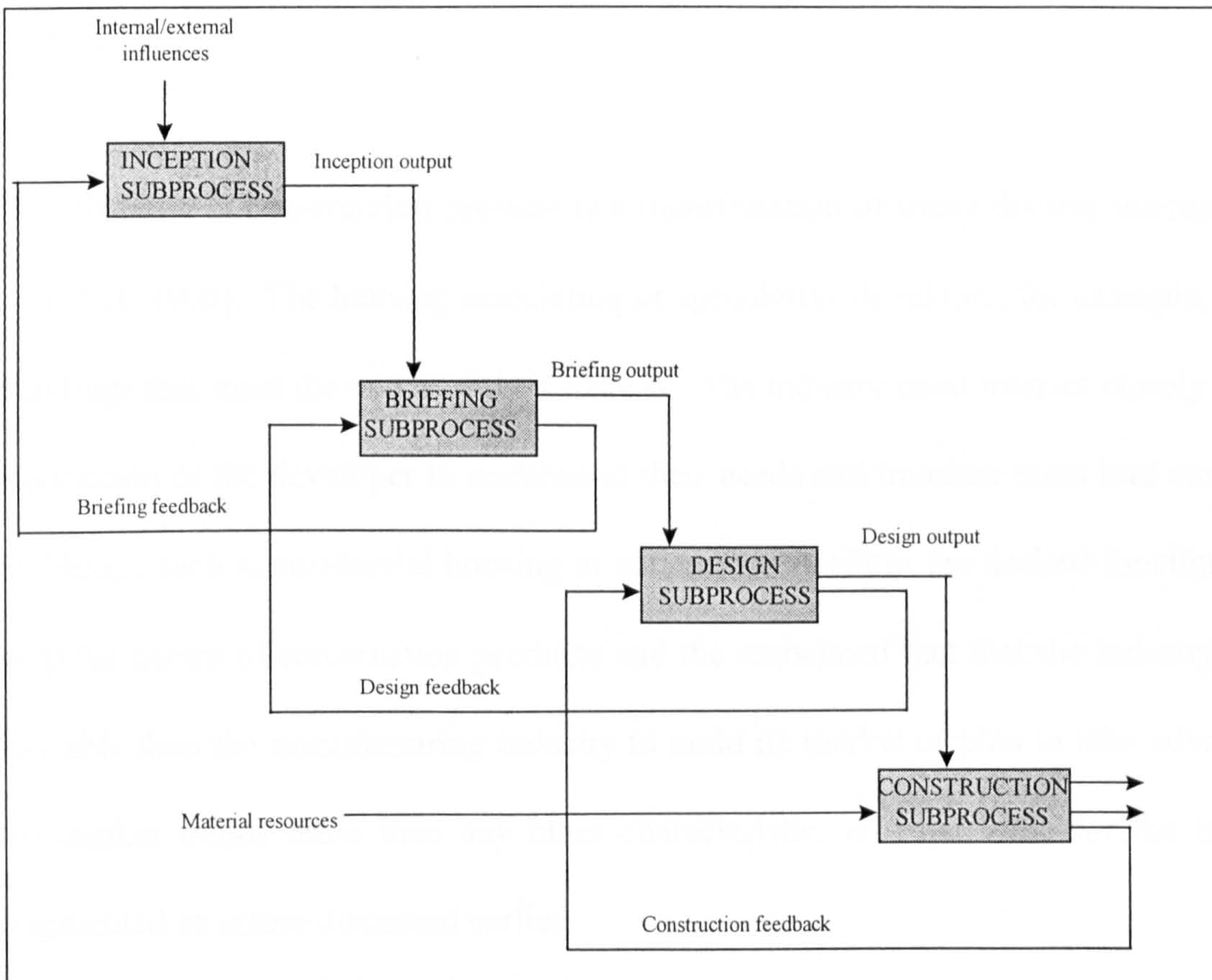


Fig. 2.1: Simplified model of the construction process (Gardiner,

2.2.3 The nature of construction product

Perhaps the most obvious distinguishing characteristic of the construction industry is the physical nature of its product. Unlike the product of other industries, construction products are diverse and uniquely characterised (Ball, 1980; Bon, 1982). Their location is fixed, they are large and heavy, custom-built, complex, take long to construct, and expensive (Turin, 1980; Ball, 1980; Nam and Tatum, 1988). In fact, village, town, city and even countries are characterised by the past and present products of the construction industry.

The diversity in construction projects is a manifestation of many diverse interests of the user (CII, 1990). The housing association or speculative developer, for example, requires buildings that meet the needs of their tenants. The industry must interact closely with the association or the developer to understand their needs and translate them into constructed buildings, such as residential housing or offices that perform the desired functions. This bespoke nature of construction products and the associated fact that the industry itself is less able than the manufacturing industry to mold its market or plan to take advantage of the market trends more than any other characteristic, is responsible for the industry's fragmented structure discussed earlier.

2.3 Construction Project Delivery Strategies

The construction process of the industry with the nature and characteristics of the product was reviewed in the proceeding section. However, in order to grasp the problems regarding performance facing the construction industry, the delivery strategy, in terms of the procurement approach and types of contract used, needs to be understood. The procurement approach in construction defines the project organisation structural set up. Whilst the type of contract used defines and allocates the role and responsibilities of the parties involved within the project. There are several procurement systems and many types of contracts in use in construction. The main types of these procurement methods and contract types used in the U.K construction industry are reviewed.

2.3.1 Procurement Systems in Construction Industry

A construction project is regarded as successful if the project is delivered at the right time, at the appropriate price and quality standard, as well as achieving a high level of client satisfaction (Naoum, 1989). For years, the inability of the construction industry to achieve these criteria has frequently been associated with the fragmentation and complexity of the industry, and the ephemeral nature of its products and its characteristics which have already been discussed. These characteristics place great dependence on the competence of the industry's organisational setting of construction (Sidwell, 1982). There has been concern, expressed for years, about the organisation of projects and the effectiveness of the project team. This concern, has for years, stimulated several reviews and studies of the construction industry and led to a series of reports identifying potential areas for changes in the industry (Emmerson, 1962; Banwell, 1964; Higgin and Jessop, 1965; Crichton, 1966; NEDO, 1975; 1976; 1978; 1983; Latham. 1994). One of the potential areas identified for change is the placing and management of contracts (Banwell, 1964). These reports and many other research studies to date have also drawn attention to the issue, and high-lighted the inefficiency of traditional delivery approach and its influence on project performance.

2.3.1.1 Traditional method

The traditional procurement method of project delivery in the construction industry has evolved and developed over the centuries, and is still the most widely used method (Frank, 1984; Masterman, 1992; 1994). Traditionally, the client contracts with a designer (either architect or engineer) for the design and specification of the project, and contractor for the construction of the project. The designer normally has some additional responsibilities for the contract administration during construction which includes inspection, monitoring progress and interpretation of design details. The contractor in turn, contracts with his own sub-contractors and suppliers, and also, often, with sub-contractors or suppliers nominated by the client.

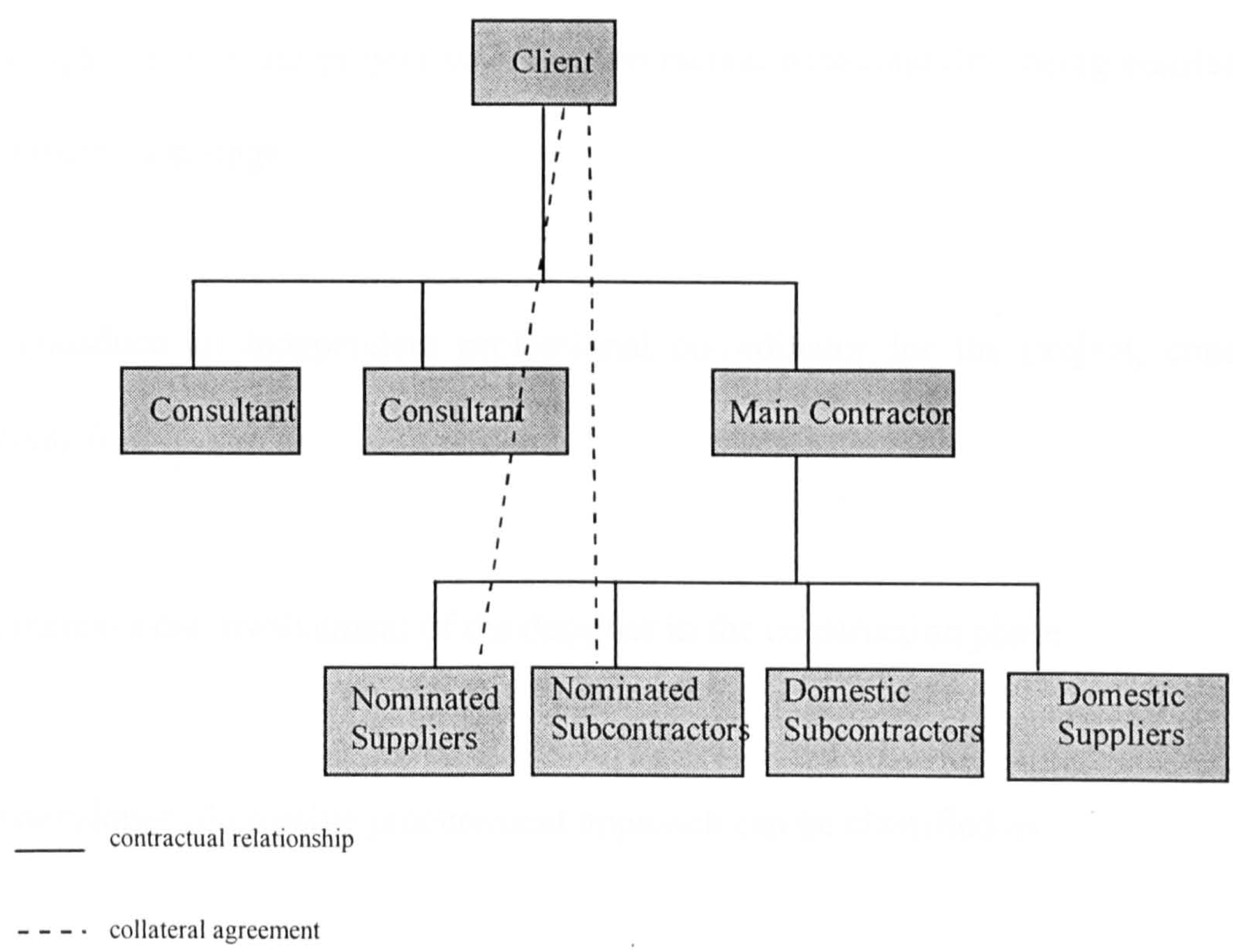


Fig. 2.2 Traditional procurement

2.3.1.2 Alternative procurement systems

Following the dissatisfaction with the traditional approach, many alternative systems have over the years been developed to improve production/delivery and performance of construction products. Those alternative approaches were based on several suggestions. Sidwell (1982) categorised the suggestions into four categories, either to:

(i) put design and construction under one commercial umbrella. In other words concentrate responsibility and accountability.

(ii) change procedures so that construction expertise is available to the designer at the design stage of the project with the contractual accountability being restricted to the construction stage.

(iii) introduce an independent professional co-ordinator for the project, concentrating control.

(iv) increase the involvement of the designer in the construction phase.

The developed alternative procurement approach can be classified as:

- design and build,
- management contracting, and
- construction management

Design and Construct Approach

The design and construct approach generally uses one organisation to handle all phases of a project from the initial briefing through to design and construction. In design and construct, unlike the traditional approach, the contractor often becomes the overall co-ordinator and manager of the project team. The approach simplifies and overcomes the divisive fragmentation of the construction process (Bennett 1991). Figure 2.3 shows the contractual relationships between the parties in the design and construct approach. The performance effectiveness of this approach is particularly evidence on project where the client can clearly specify his needs and requirements (Rowlinson, 1986). Other benefits of the design and construct approach has been identified in series of research investigation of the performance of the system (Barrie, 1981; Sidwell, 1982; Nahapiet and Nahapiet, 1985; Rowlinson, 1986). Nahapiet and Nahapiet, (1985) highlighted three main benefits of the system from their studies:

(i) it provides a single point of responsibility between the client and the design construct contractor;

(ii) it eases communications between the various specialists groups who are all part of a single organisation; and

(iii) it is also believed that the approach provides a high degree of flexibility and response to changes at all stages of the project.

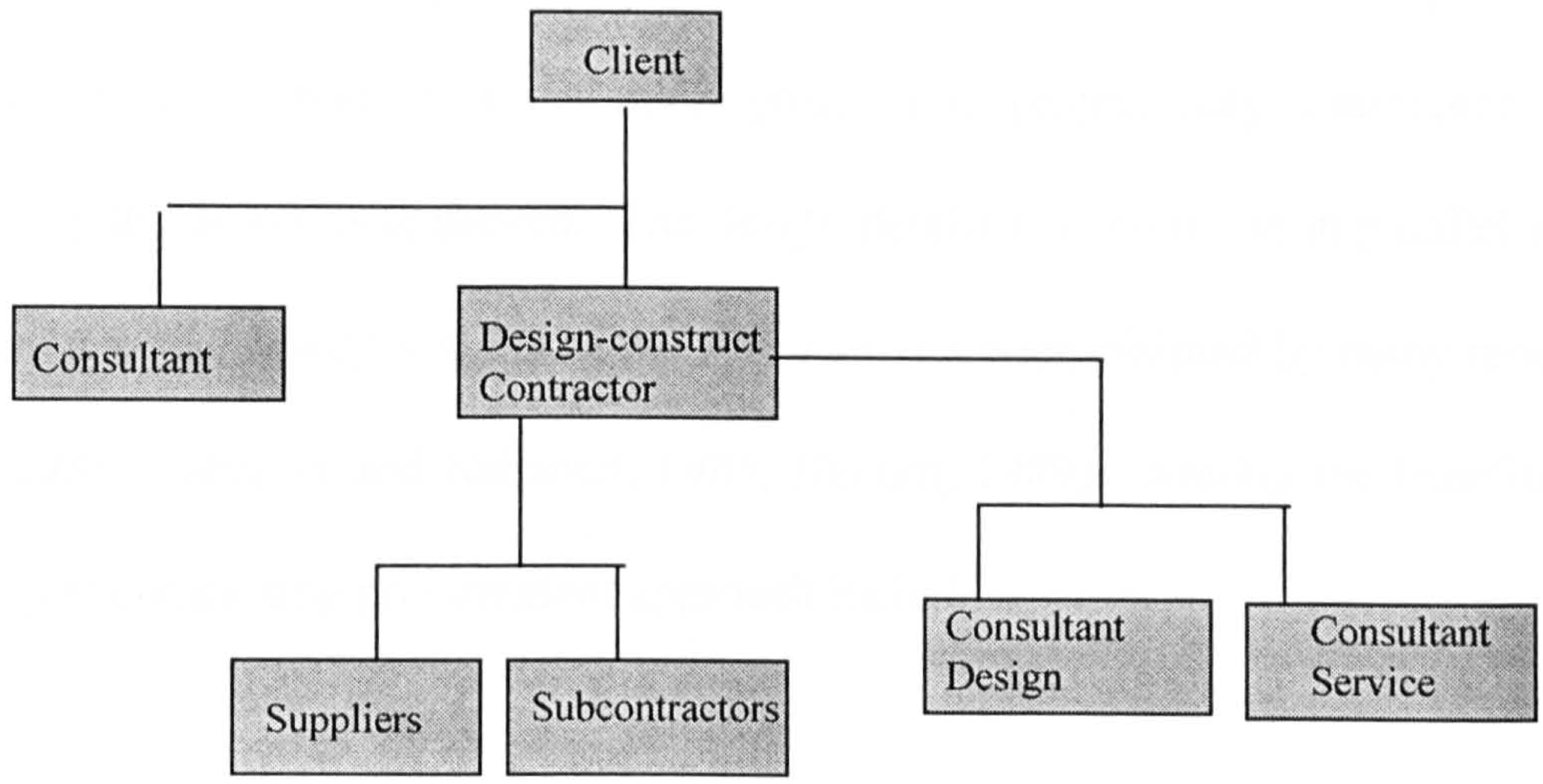


Fig. 2.3: Design and construct procurement approach

Management Contracting Approach

Management contracting procurement is another alternative to the traditional approach; the client appoints a management contractor, who is usually a general contractor, to work alongside the other professional consultants. The aim behind this approach is to ensure that the construction expertise of the contractor is incorporated into the design. The role of the contractor is solely to manage the construction activities according to the interest of the client without actual involvement in the construction work, instead contracts out the work packages to work contractors on behalf of the client. The contractual role of the contractor and the other parties involve in a typical management contracting approach is shown in figure 2.4.

The management contracting approach is best suited for large and very complex projects where speed of completion is the main goal. The project may commence on site immediately the design is approved. The design details may continue in parallel with the construction work. Many benefits of the approach has been claimed by many researchers (Barrie, 1981; Nahapiet and Nahapiet, 1985; Naoum, 1989). Among the benefits of the management contracting procurement approach includes:

(i) it permits the phased construction, allowing for greater speed of project delivery;

(ii) it maximises competition for each of the work package subcontracts which results in savings to compensate for the extra fee required;

(iii) it encourages the creation of good, harmonious relationships between the parties involves.

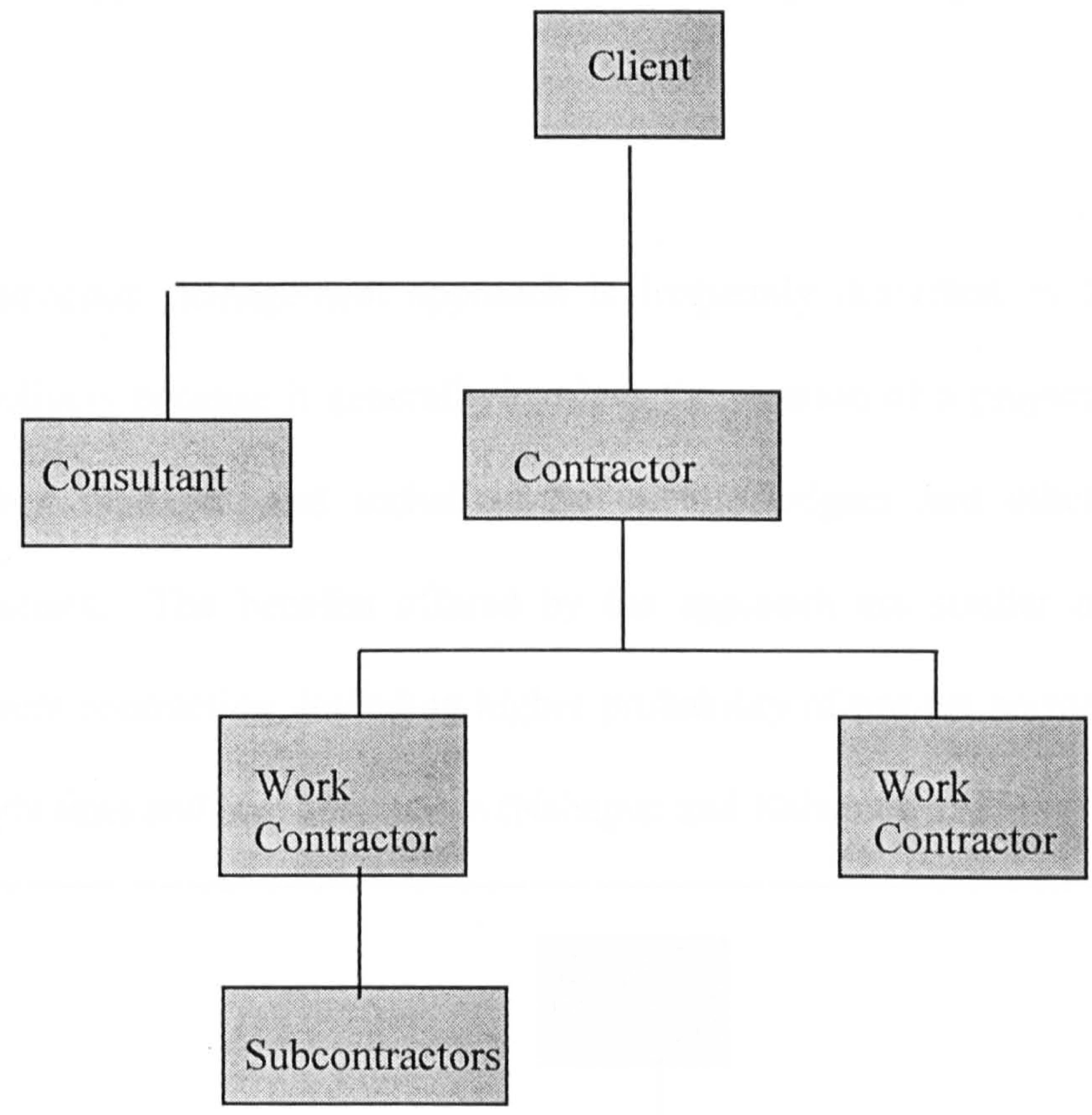


Fig. 2.4: Management contracting procurement approach

Construction Management

The final alternative project delivery approach is the construction management procurement approach. Construction management system is similar to management contracting; like the contractor under management contracting, the construction manager as a consultant is working for the interest of the client who appointed him as an agent. The construction manager is responsible for the co-ordination and control of all aspects of the project to achieve the client's stated requirements. A model of construction management approach with the contractual relationships of the parties is shown in figure 2.5.

The construction management approach is frequently described as team approach to project delivery because it generally involves the creation of a project group led by the construction manager, and including the client, designer and other consultants and subcontractors. The benefits offered by the approach are similar to that offered by management contracting, including higher probability of project performance attainment within tight time and cost constraints (Nahapiet and Nahapiet, 1985).

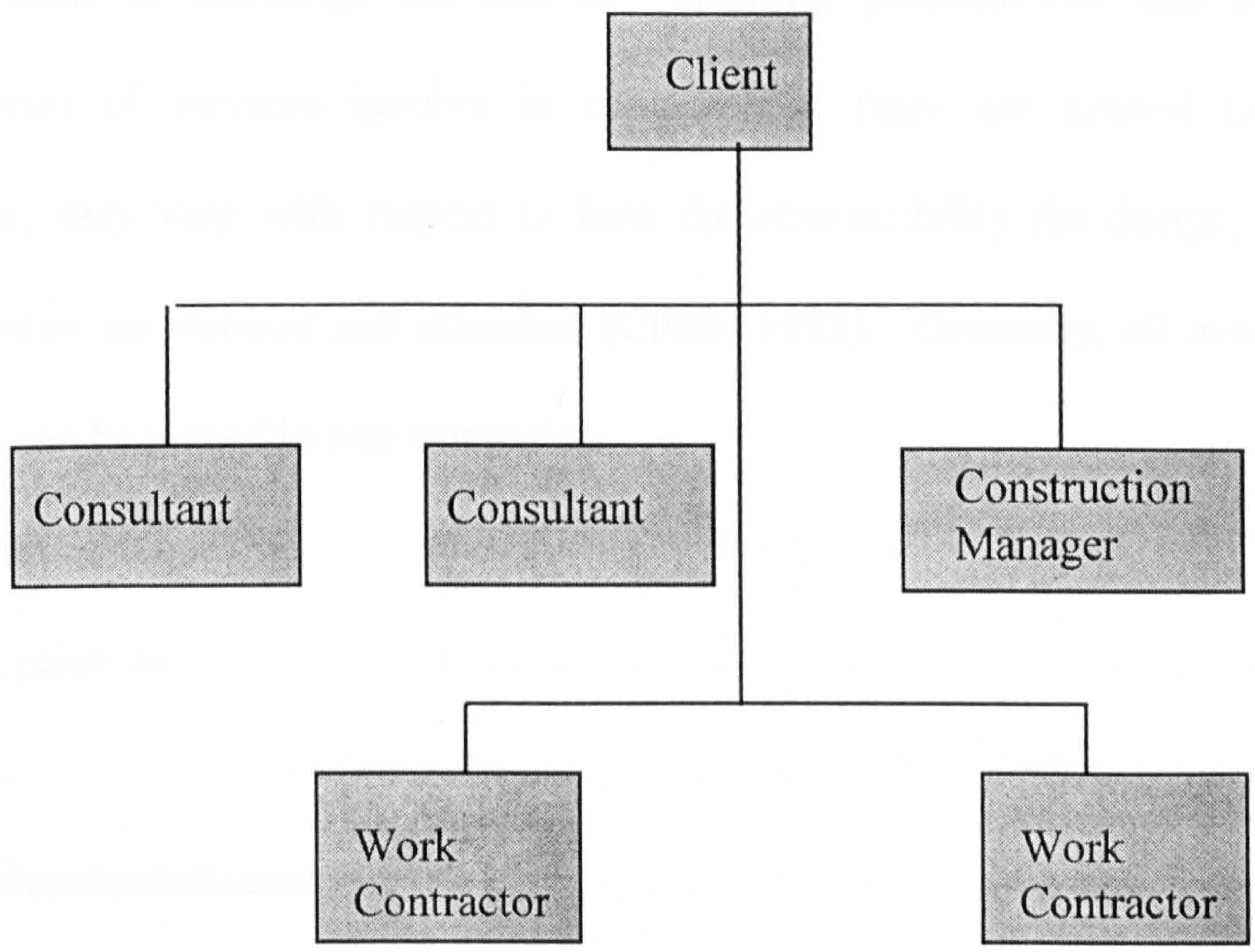


Fig. 2.5: Construction management procurement approach

2.3.2 Contract types

Contract is another important requirement for the delivery of any construction project. It creates an effective mechanism for bringing together the contribution of the wide range of design, construction and other specialists expertise required for the construction of the project (Nahapiet and Nahapiet, 1985). The contract defines the role and responsibility of those organisations and manages the inter-organisation relationships. A key decision for any construction client is deciding the type of contract to adopted.

As a means of exchange the aim of ensuring predictability and security in the transactions of services involve in construction, there are several types available. However, they vary with respect to how the responsibility for design, planning, and construction are defined and allocated (CIOB, 1982). Generally, all available types of contract can be placed in two categories:

- fixed price, or
- negotiated/reimbursement

2.3.2.1 Fixed price contracts

Fixed price contracts are the basic and most traditional types of contract in the construction industry. Ideally under the fixed price contracts, the project design is finished before the contract is award (CII, 1986). In other words, the project details are completed, including the client's full commitment and the design is comprehensively detailed with a full specification. The contractor, in return, agrees to construct the project for a fixed price.

There are two primary types of fixed price contracts: the lump sum and the unit price. Typically, any types of fixed price contract place responsibility for the co-ordination of the various organisations and specialists involved with the architect (or engineer). The contractor, appointed through one form of tendering (in competition or directly), does the work for a fixed price and a fixed period. Damages for overrun are incorporated into the contract.

Lump sum contracts

Lump sum contracts are probably the most common type of fixed price contracts in use in construction industry in U.K. On a well-defined project, lump sum contracts provide the client with certainty of final cost and time of the project completion (Nahapiet and Nahapiet, 1985; CII, 1986). The contractor's profit can be increased by efficient work ensuring timely completion of the project once the design has been finalised. This type of contract, however, does not encourage variations of the work once the contract is awarded.

Unit price contract

Unit price contract was developed in effort to make the fixed price contracts more flexible and less sensitive to variations (changes) if required. Under the unit price method, prices are given for the quantity and items of work involved. So if a variation in the actual quantity of a particular item of work occurs, then the pricing is based on the predetermined unit price. Thus ultimate cost of the project may not be known, but the chance of over payment is reduced by detailed computation of actual work items and costs through careful measurement and determination of the true quantities of work (CII, 1986). Thus, this method requires the client (or his representative) to be involved and to control the construction of each item of work.

2.3.2.1 Negotiated/Cost Reimbursable Contract

Negotiated contracts are usually used when the definition demanded by a fixed price contract cannot be met (Nahapiet and Nahapiet, 1985; CII, 1986; Masterman; 1993). The client or his representative (quantity surveyor or cost consultant) negotiates a set of conditions and prices with the selected contractor on the basis of the scheme design and specification of the project. In essence, the client reimburses the contractor for the construction costs plus a fee for his service. It is claimed that negotiated types of contract with clearly defined procedures, covering payment, project goals, and communication, foster good working relationships between the client and the contractor (CII, 1986). Like fixed price contracts, there are several types of negotiated cost contracts. The most commonly used ones are: cost plus percentage fee; cost plus fixed fee; and target price.

Cost plus percentage fee

A cost plus percentage fee contract is suitable for project whose work scope cannot be properly defined initially. The contractor proceeds with the work as design becomes available, receiving a fee based on the final costs of the project. Since it is not to the contractor's advantage to minimise costs, care is required to control the project expenses. Over-costs of the work are often contained through the use of an incentive plan to encourage performance as well as minimising costs (CII, 1986). However, good co-operation and communication between the parties is necessary for best results.

Cost plus fixed fee

Cost plus fixed fee contracts are similar to the cost plus percentage contracts in their application. The contractor is paid the actual construction cost plus a fixed pre-agreed fee for his services. The project must be well enough defined so that a reasonable estimate of the project cost and the contractor fee can be made. This type of contract encourages the contractor's diligent efforts to finish the project in time (CII, 1982). However, If more incentive is desired, a profit sharing plan based on cost saving can be use.

Target price

Target price contract is another type of reimbursement contract. Within target price contracts, unlike the other reimbursement contracts, the client rather than defining the project cost sets a target price for the project. To do this, the client and the contractor sometimes negotiate an estimated cost and profit and a formula for calculation of the final cost of the project and profit. The contractor gets paid for the construction cost and compensated, through the agreed formula, for his services. If, however, the final cost of the project is below the target, the contractor make more profit but, if it is above the target, the contractor receives less payment.

2.4 Risk and Uncertainty of Construction Projects

Risk and uncertainty are inherent in all construction projects no matter their size, large or small (Thompson and Perry, 1992). Crichton (1966) found that nothing contributes more to the construction industry's ineffectiveness than uncertainty, since it provides the ideal environment for conflicts. The production of construction projects as a process which involves a multitude of activities, some occurring serially, others in parallel, provide an ideal environment for risk and uncertainty. Uncertainty by the client in properly defining his need, uncertainty by the designer in identifying the optimum solution to the client's need, and uncertainty by the contractor in predicting accurately the true cost of the project (McGowan et al, 1992).

The majority of the clients undertake construction projects mainly as an investment. But the changes in the economic conditions of the past two and half decades with the rapid technological developments has made construction funding more complex, particularly in the private sector (Flanagan and Norman, 1993). These changes, among others, have over the years increased the demand for flexibility in construction process to allow variations (changes) to be made to the project to take advantage of any new changes in the economy or available technology. Hence, the increase in the risk and uncertainty of the client's project needs.

The architect (or engineer) as the client's adviser, along with the other member of the consulting team, offer services to the client on his investment in construction, the design, cost, contract strategies and all the other facets of dealing in construction project (Flanagan and Norman, 1993). Unfortunately, lack of understanding and failure of the industry to educate their clients in regard to how the industry operates or the full implication of their decisions, often leads to a number of variations being issued during the construction stage of the project and negotiation or settlement of payment for them (Cherns and Bryant, 1984; Bresnen and Haslam, 1991; Power-Smith, 1986; Flanagan and Norman, 1993). In essence risk and uncertainty is caused by the designer in lack of definition of the client's needs; this is common on many construction projects.

It is these risk and uncertainties and those associated with the unstable environment of the project that fosters the growth of adversarial relationships between the parties and causes failure to keep the project within the budget, achieve the required completion date, and achieve other performance objectives.

Unfortunately, the construction industry as a service industry, has a poor reputation for coping with uncertainty of its production process and its environment (Thompson and Perry, 1992). As a result many projects failed to meet the time and cost requirements. NEDO (1975) in a report on performance of public projects, found that one in six projects overran by more than forty percent of the original project duration, and a significant number by more than eighty percent. Time and cost overruns can invalidate the performance case for a project, turning carefully organised project into disarray resulting in disruptions, disputes, claims, and often, litigation.

As a result of the inevitability of risk and uncertainty of construction projects, much research has, over the years, been focused on the review and improvement of management of project uncertainty (Perry and Hayes, 1985; CII, 1988 , 1989; Thompson and Perry, 1992; McGowan et al, 1992). The main emphasis of these studies is on the contribution which can be made to the avoidance of cost and time overruns commonly associated with construction projects.

Various authorities and researchers have offered a broad definition of risk. Cooper and Chapman (1987) for example, defined risk as exposure to the possibility of economic or financial loss or gain, physical damage or change of duration, as a consequence of the uncertainty associated with pursuing a pre-determined course of action.

CII (1989) defined risk in terms of uncertainty as a set of all potential outcomes of a project, both favourable and unfavourable. Unfavourable outcomes represent risk whereas those which are favourable represent opportunity (if any). In estimating the total cost of a project, for example, a number of potential outcomes exists, ranging from the best potential, underrun, to the worst, overrun. All of those potential unfavourable outcomes (i.e. cost overruns) will represent a risk to the project.

Risk management concept is not unique to construction, its development probably owes much to other industries such as insurance. APM (1992) defined risk management as a process which enables the analysis and management of risks associated with a project. Properly undertaken, it will increase the likelihood of successful completion of the project. As a process, risk management usually involves several stages of decision making activities aimed to remove or reduce the risks which threaten the achievement of the project's objectives (Perry and Hayes, 1985). One approach identified as suitable for construction project risk management involves two distinct sequential stages:

(i) risk analysis, and

(ii) risk response

2.4.1 Risk analysis

The goal of risk analysis is to define a set of key risk sources or factors which apply to a particular project, according to it type, environment, stage of development, etc., and to assess their relative impact on risked consequences that could result in a failure to satisfy project objectives (Berkeley et al, 1991). Risk analysis is generally split into two stages; risk identification, and assessment stages (APM, 1992; Thompson and Perry, 1992).

The identification of the risks associated with a project is a necessary first step in risk analysis (Perry, 1986). The need to identify project risks and anticipation of the possibility of their occurrence and understanding of their likely impact on the project has led to much research aimed at identifying risk sources or factors. Thus sources of risk for a client will differ from that of a contractor or consultant. For example, CII (1988) identified ninety-six risk sources for contractors. However, there are primary risk sources common to all parties involved with a construction project. Perry and Hayes (1985) identified nine of those primary risk sources (Table 2.1). These risks can result from three conditions or situations; *known*, *known-unknown* and *unknown-unknown* conditions (CII, 1988).

Table 2.1: Primary sources of risk in project (Perry and Hays, 1985)

Physical
Loss or damage by fire, earthquake, flood, accident, landslip
Environment
Ecological damage, pollution, waste treatment
Public enquiry
Design
New technology, innovative applications, reliability, safety
Detail, precision and appropriateness of specifications
Design risks arising from surveys, investigations
Likelihood of change
Interaction of design with method of construction
Logistics
Loss or damage in the transportation of materials and equipment
Availability of specialised resources- expertise, designers, contractors, suppliers, plant, scarce construction skills, materials
Access and communications
Organisational interfaces
Financial
Availability of funds, adequacy of insurance
Adequate provision of cash flow
Losses due to default of contractors, suppliers
Exchange rate fluctuations, inflation
Taxation
Legal
Liability for acts of others, direct liabilities
Local law, legal differences between home country and home countries of suppliers, contractors, designers
Political
Political risks in countries of owner and suppliers, contractors-war, revolution, changes in law
Construction
Feasibility of construction methods, safety
Industrial relations
Extent of change
Climate
Quality and availability of management and supervision
Operational
Fluctuations in market demand for product or service
Maintenance needs
Fitness for purpose
Safety of operation

Known condition risk: The common risks from the known condition are typically those which can be explicitly or implicitly accounted for in the project estimate. They generally involve a range of outcome of high frequency and relatively low severity. Labour productivity, for example, is a known condition risk on a construction project. Using a combination of past project data and experience, productivity judgements can be made for any particular work activities.

Known-unknown condition risks: Those are neither explicit nor normally expected, but are foreseeable and possible. Generally, they tend to be discrete events with low frequency of occurrence but high severity impact when they occur. Typical example is the extreme bad weather (such as floods, hurricane or tornado), extreme adverse labour activities (i.e. strike) or material shortage due to embargo or sudden regulatory interventions.

Unknown-unknown condition risks: Those risks cannot be identified in advance but their potential can be acknowledged. Typical example are variations (i.e. changes or modifications) which are generally acknowledged as part of the construction process but their specific nature or magnitude cannot be known before the project commences.

However, for the identified risk sources or factors to be useful, in practice, must meet two specific requirements (Berkeley, el al, 1991);

(1) it must be reliably quantifiable in relation to the risk(s) in terms of an ordering of levels (i.e. 'low', 'medium' and 'high' or 'present' vs 'absent') of a specific risk, and

(2) it must be observable in the context of the particular project.

These requirement need to be met for the identified risk factors to be linked to the next stage of the risk analysis process- risk assessment.

Risk assessment involves quantitative analysis of the identified risk factors' effect and impacts on the project cost and time parameters (Perry, 1986). A number of risk assessment techniques have been theoretically developed over the years but their practical applications on construction projects has been limited mainly to larger capital projects. The main techniques currently in use are:

- traditional (or conventional);
- sensitivity analysis;
- probability (or monte carlo simulation);
- decision tree;
- influence diagrams;

2.4.1.1 Traditional method

Traditional risk analysis method rely on the experience and judgement of the analyst (Chapman, 1990). It is explicitly a subjective method whereby the analyst apply his experience and judgement to arrive at a contingency value to be allowed on the estimates for the project cost or time. This method is the least versatile and most commonly used method in practice, especially, on building projects.

The primary input need of the method is only the experience and judgemental ability of the analyst. The method, therefore, have no inherent ability to handle complexity or explanation for the derive contingency value (Yeo, 1992).

2.4.1.2 Sensitivity method

The sensitivity analysis determines the effect, on the whole project, of changing one of its risk variables. It involves repetitive calculation of the effect of each of the identified risk variables, in order to establish those which have a potentially high impact on the project outcomes in terms of cost and time (Thompson and Perry, 1992). The importance of this method is that it often highlights how the effect of a single change in one risk variable can produce a marked difference in the project outcome. However, there are two main weakness of the sensitivity analysis method (Perry and Hayes, 1985). One weakness is that the variables are treated individually in the analysis. This leads to severe limitations on the extent to which combinations of those variables can be assessed directly from the data. Lastly, the analysis gives no indication of the anticipated probability of occurrence of any of the risk.

2.4.1.3. Probability analysis method

The probability method specifies a probability distribution for each of the identified risks and then considers their effects in combination on the project outcome(Perry, 1986). The method relies on the random calculation of values that fall within a specified probability distribution often described by using three estimates: minimum or optimistic, mean or most likely and maximum or pessimistic. The overall outcome for the project is derived by the combination of values selected for each one of the risks. The simulation is repeated a number of times, between 100 to 1000, to obtain the probability distribution of the project outcome.

2.4.1.4 Decision tree analysis method

Decision tree is a graphical means of bringing together the information needed to make a project decisions and show the present possible course of action and all future possible outcomes (APM, 1992). The method is employ in situations where the decision to be model is best represented as a sequence of related decisions. The decision trees analysis produces both the best course of action out of the alternatives available to the decision maker with probability values indicating their likelihood of occurrence. The method requires the probabilistic measures of chance events and the payoffs at the ends of the tree paths.

2.4.1. 5. Influence diagrams analysis method

This method is a relatively new technique of risk assessment. The influence diagrams provide a powerful means of constructing a model of the issues in a project which are subject to risk (APM,1992). The influence diagrams method, akin to decision tree method except that they are more versatile, model a decision problem and a way of solving the problem. The method is useful when modelling complex interactions among decision variables and expected values for the modelled parameters (Diekmann, 1992). Typical influence diagram is shown in Figure 2.6. Influence diagrams require a detailed representation of the relationships among the variables (the influence), and conditional probability statements in discrete form.

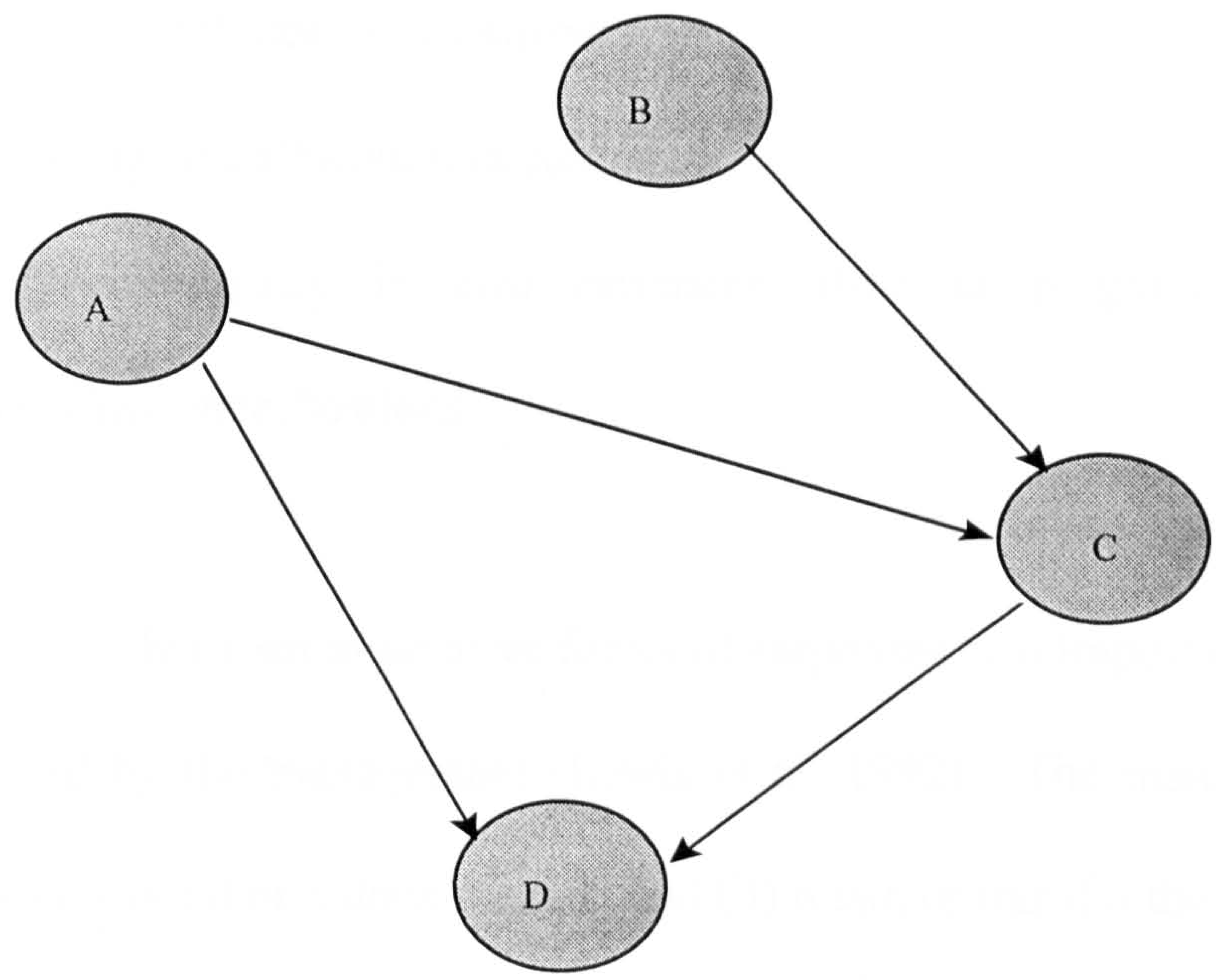


Fig. 2.6: A typical influence diagram

2.4.2 Risk Responses

This stage of the risk management uses information collected during the risk analysis stage for the management to formulate how to respond to the identified and analysed risks (Thompson and Hayes, 1992; APM, 1992). The responses can take many different forms. On a single project, for example, several different responses may be adopted by the management, depending on the type of the risk. The risk responses process involves:

- identifying preventive measures to avoid a risk or to reduce its effects
- establishing contingency plans to deal with risks if they should occur
- initiating further investigations to reduce uncertainty through better information

- considering risk transfer to insurers
- considering risk allocation in contracts
- setting contingency in cost estimates, float in programs and tolerances in performance specifications

When deciding between alternative forms of responses two important basic decisions are kept in mind by the management (Lewis et al, 1992). The management must decide whether to: (i) avoid or reduce the risk, and (ii) retain or transfer the risk and its impact.

The management decisions to avoid a particular risk on a construction project may mean the abandonment of the project entirely. However, risk avoidance and the reduction of risk probability and impact requires a technical response (Lewis et al, 1992). Such response may include a change or several changes in the design or further development of the design, or the acquisition of more complete information, for example, by undertaking or extending the site investigation.

The principal means for transferring and allocating construction project risks is through the construction contract. Perry (1986) identified the four most common routes of risks transfer or allocation on construction project based on the contract. The four routes are:

(i) client to contractor or designer,

(ii) contractor to subcontractor,

(iii) client, contractor, subcontractor or designer to insurer,

(iv) contractor or subcontractor to surety.

Risks are transferred through the contract primarily because it offers potential for shrinking the risks and for active collaboration by all the parties involved in reducing their effect (Perry, 1986). In choosing the appropriate route for risk transfer through the contract, a number of factors need to be considered. Those factors, according to Perry, would include:

- which party can best control the events that may lead to the risk occurring,
- which party can best control the risk if it occurs,
- whether or not it is preferable for the client to retain an involvement in the control of the risk,
- which party should carry the risk if it cannot be controlled,
- whether the premium to be charged by the transferee is likely to be reasonable and acceptable,
- whether the transferee is likely to be able to sustain the consequences if the risk occurs,
- whether, if the risk is transferred, it leads to the possibility of risks of a different nature being transferred back to the client.

The essential characteristics of any transfer response chosen is that when the risks occurs, their consequences are shared with or totally carried by, a party other than the client. Thus, the client would be expected to pay a premium for the privilage.

2.5 Summary

The construction industry holds an important position in the British economy. It is not only a large industry but also has unique characteristics in comparison with other manufacturing industries.

Attention is drawn particularly, to the structural complexity of the industry, its construction process and the uniqueness of the project itself. The construction industry, as a manufacturing industry, is structurally fragmented with a large number of small and specialised organisations. As a result, the industry relies on the skills and expertise of different professions and organisations in the course of its production.

The traditional and alternative contracting system within the construction industry are examined through the identification and description of various procurement methods and contractual arrangements which exist and which are commonly employed. The traditional procurement method, thus remains the most dominant method, but the uses of other alternative procurement methods, such as design and built and management contracting has been gaining popularity particularly in response to the expressed concern and need for flexibility and accommodation of risk and uncertainty, particularly those that are unavoidable, during the project construction process.

However, the fragmentation and complexity of the industry, and the ephemeral nature and environment of the projects, place a great dependence on the competence and effectiveness of the project team in setting up the construction process and management of their risks and uncertainties through to successful completion of the project.

The risk and uncertainty inherent in any construction project arises from a variety of sources and varies both in likelihood of occurrence and in potential impact on the success of the project. For example it is virtually certain that variation orders will be issued during the construction of the project, but their magnitude and when or where they will occur are relatively unknown prior to their actual occurrences.

As the successful performance of any construction project depends upon how the inevitable risk and uncertainty of the project, particularly variations, are properly managed, this research specifically focuses upon the occurrence and magnitude of variations on construction projects in the U.K.

CHAPTER THREE

THE ANATOMY OF VARIATIONS ON CONSTRUCTION PROJECTS

3.1 INTRODUCTION

The construction industry, in common with most industries, is beset with problems of efficiency and productivity. These problems are perhaps much greater in the construction industry than any other industry due to the complex nature of the industry and the unique characteristics of its end products (Hibberd, 1980).

There have been a number of contributions to our knowledge of the construction industry with regards to its structure, process, products, and the risks and uncertainties of its delivery systems (see chapter one) and the problems of its organisational effectiveness. In spite of those studies (Emmerson, 1962; Banwell, 1964; Crichton, 1966; NEDO, 1975), much research is still needed to be carried out, especially on contract performance, cost and time overrun, claims and disputes. It is evident today, more than ever, that claims and disputes in construction have become endemic, especially those caused by variations. Variations and their effect on productivity were one of the major problems highlighted by Sir Michael Latham (1993).

The word 'variation' in a construction context, is generally employed in two senses. Firstly, it means an alteration, whether by addition or omission, to the physical work content. Secondly, the word may denote a change in the contractual terms upon which the relevant work is to be performed (Dorter, 1991). The former sense in which the word is used is the most common and proper in the construction industry, and therefore, the concern of this paper. A variation in this sense is described by Bromilow (1970) as "the extent to which the contract is varied between the time at which it is let and the issue of the certificate of practical completion".

The magnitude and inevitability of variations in construction, has raised questions and concern about the inadequacy of the industry's management of the design and construction process. This view is supported by all the past investigations into the problems facing the industry (Emmerson, 1962; Banwell, 1964; Crichton, 1966). Abrahamson (1979) in his book *Engineering Law and the ICE Contract*, stated that 'most of the employment given to the legal profession by engineering work is to do with disputes about variations'.

Similarly, Bromilow (1970) stated that variations are the major causes of many problems in construction contracts and that they are the source of delays and cost overrun on construction projects. This conclusion is supported by other researchers (Hibberd, 1980; Choy & Sidwell, 1991). Hibberd suggested that 'to know how to deal with variations, one must first understand their nature and why they arise'.

This chapter reviews past empirical studies and investigations concerning variations and relevant subject area to assesses the extent to which the problems as a risk factor have been resolved and managed. The discussion in this chapter is centred on the main focus of the research, the problem of variations. In line with the research objective, the discussion is centred on, the sources or causes and nature of variations, factors influencing the occurrence and magnitude of variations, and construction management of variations and their impacts.

3.2 Source of Variations

Semple (1971) stated that 'variations are definitely not accidental happenings but they are definitely produced by the architects'. Other research supports this view to an extent, for example Bromilow (1970) in his research based on analysis of data collected on 248 projects in Australia, identified seven sources of variations. From Bromilow's report, the client is identified as the most prolific source of variations on construction works (49%) with the second major source being the design team (26%).

Hibberd (1980) from his research in United Kingdom, identified the major sources of variations on construction works as inadequate consideration of design (25%), defect in the documentation (16%), and design initiated (19%). Contrary to Bromilow's findings in Australia, Hibberd's research findings attributed only 10% of variations to the client. Surprisingly however, other research in UK. (Langford et al, 1986) found the majority of variations to be caused by the design team (72%).

Recent research in Australia by Choy and Sidwell (1991), contrary to Bromilow's findings, identified the designer as the major sources of variations. The research also identified errors and omissions in bills of quantities as another main source of variations on construction contracts.

Comparing Bromilow's categorisation of variation sources with that of Hibberd, a degree of commonality can be established, however, further analysis of the two sources shows that there are some differences. Client sources, according to Bromilow (1970), consist of straight-out additions to the work, changes in requirement or materials or methods. While Hibberd (1980), divided this category into two, 'client forced', and 'client choice'. Client-forced refers to changes caused by circumstances of events outside the control of the client. Client-choice refers to changes which are not directly the result of events outside his control.

Designers (i.e., architect, engineer, and others associated with the design) according to Bromilow (1970), generate variations due to faulty design, changes brought about for a variety of reasons including compensation for other changes in order to keep the overall cost down. Hibberd (1980) attributed those variations to the designer exercising his discretion with regard to matters for which he has responsibility whether or not they have been sanctioned by the client. However, sources such as defects in design, inadequate consideration of design and incorrect assessment of the brief, all of which Bromilow (1970) attributed to the designer, were separately categorised under "management" source of variations by Hibberd (1980).

The differences in the sources identified by both researchers are based on the causes and nature of variations. The majority of variations generated by the client, were straight additions to the work. This is followed by changes in requirements or materials or methods of construction. Parts of those changes, undoubtedly, were made to save money to pay for additions already generated or contemplated while at the same time attempting to keep down the overall cost.

It is perceived in the industry that quality is produced when the designer is allowed adequate time to continue his search for a satisfactory design solution. However, in practice contract documents are often prepared based on an incomplete design with resultant variations after contract award.

3.3 Magnitude and Impact of Variations

In construction projects, it is an accepted fact that variations will occur during the course of the work. The magnitude of variations on a project can be measured in terms of their costs (i.e. gross value) and number of occurrences (i.e. frequency) on the project. The gross value of variations can be calculated from the total sum of the net value of each variations. Bromilow (1970), based on data from his study, developed two formulae which can be used to determine the magnitude of variations (in terms of cost and frequency). However, there is no indication of the uses of the formulae in practice to test their validity.

In practice, the contentious area when valuing a variation, is the time and cost impact on the project. The costs impact are not the direct costs of performing the varied works, but rather the additional costs incurred in performing the work affected by the delay and disruption resulting from the changes (Moselhi et al, 1990). The impact costs can be broadly classified into two categories; 'time-related' and 'productivity-related' costs.

The time-related costs are those costs associated with extended duration, i.e. extension of the project beyond the original contractual completion date. These are less difficult to establish, once the time extension has been quantified. Time related costs in connection with an extended duration should be based on a contractor's actual cost, however in practice, the pre-agreed costs (i.e. the preliminaries) are sometimes used (Potts, 1986). Unlike time-related costs, there are no established methods to prove how productivity-related costs are determined in practice. However, a comparison of the contractor's rates of production being achieved before and after the delay/disruption can prove useful.

3.4 Factors Influencing Variations

Previous research studies on construction project organisation and management has largely involved the modelling of the construction process and measuring the cost and time performances of different projects. Notably Walker's (1981) client-oriented model based on the concept of system theory, related client's objectives to managerial actions through integration of the client's organisation and the building process in relation to successful completion of the project.

Sidwell (1982), also developed a model linking client and project characteristics with other project factors, to examine the respective influences and relationships with the project performance of cost and time. It is suggested that correct matching of those organisational factors with both the client and project characteristics, can improve the building project performance.

Other research work of a similar nature included: Bromilow & Henderson (1971); Morris (1972); Ireland (1985); Nahapiet & Nahapiet (1985); Bresnen & Haslam (1991). For example, Bromilow and Henderson (1971) compared time and cost expectations with the real time and cost and the number and value of variations as a measure of project performances. Contrary to this approach, Sidwell (1982) used measures of client cost and time satisfaction as the measure of project performance.

3.4.1 The Client Characteristics

The client, i.e. the project sponsor or initiator, can range from an individual, building a single building with little or no knowledge of construction and limited funding, up to a large complex multi-national organisation with large amount of resources and access to a great deal of experience and management expertise. Thus, initially variations may not be the concern of the client but as a result of his decisions variations will be instructed with both cost and time implications. The client characteristics i.e. type of client, and experience/sophistication of client, will have considerable influence on the project performance outcome (Bromilow, 1970; Sidwell, 1982; Bekr, 1990).

3.4.1.1 Type of client

The type of client 'variable' is intended to distinguish between, public and private clients. Public clients include local or central government and nationalised industries who frequently require construction projects for the purposes of healthcare, education, transport, administration and housing. Thus, public clients are the major source of construction works but limitations such as limited funds, fixed annual budgets, and public accountability rules will influence their decisions on the annual expenditure on construction.

The RICS (1984) subdivided private sector clients into two; owner occupiers and speculative/developers. The owner occupier clients range from multi-national firms to small privately owned companies, mainly engaged in commerce and or industry. The majority of this client group may not be familiar with the building process as construction is not their business but they need buildings to produce their own products or services. Speculative developers on the other hand build for rent or sale; clients in this category are generally efficient in their dealing with the construction industry due to the fact that construction is the large part of their business risk and they are regularly involved in the process.

3.4.1.2 Experience/sophistication of client

Another important characteristic of the client that will influence project cost and time performance is the client's own level of 'sophistication'. Higgins & Jessop (1965) defined a sophisticated client as the person or organisation who knows a good deal about the building process. Closely linked as a measure of client sophistication is their experience of construction as mentioned earlier. For instance the majority of public clients and private speculative/developer clients will be aware of the impact of variations ordered during the construction period and their resultant effects on time and cost performance.

3.4.2 The Project Characteristics

Apart from a few exceptions, construction projects are generally unique, they accommodate different designs, different construction methods, and are built on different sites in different locations. Each projects has different characteristics which will influence how the project is initiated, designed, organised and managed and the final outcome of the finished project.

Past research and investigations into the construction process and organisation has identified and quantitatively measured the relationship and influence of project characteristics on the organisation and performance of the project (Morris, 1972; Sidwell, 1982; Bennett, 1983). The project characteristics identified included the following: project size, project time/duration, project type, project complexity, and project location.

3.4.2.1 Project Size

The size of a project is the first variable to be considered in connection with construction project. Size is widely accepted as the most important variable in determining appropriate management strategies (Handy, 1976). This view is supported by the previous project organisation and management researchers in the construction industry. Sidwell (1982) identified project size along with other variables as a major variable influencing project performance. Project sizes are denoted either by their physical attributes or their value. Large projects are generally complex and this complexity will influence the organisational structure and management structure.

3.4.2.2 Project Type

The project type usually denotes the function or purpose of the finished project; whether residential, commercial, industrial, education, health or recreational. Both the physical and monetary value of the project will also influence the organisational design and management and the performance of the project.

3.4.2.3 Project Time

The time for completion of the project is another important characteristic which will have a significant influence on project performance. The duration required for the physical construction of a project may change as the design and construction process proceeds. Any changes, whether of addition, deletion or substitution of one component for another, or the addition or correction of any information, will have an impact on the timing of the project.

3.4.2.4 Project Complexity

The complexity of the project is another characteristic likely to influence the number and magnitude of variations on construction projects with a resultant significant impact on the project performance (Bromilow, 1970). The concept of complexity however, have been analysed and discussed by many researchers in the past (Morris, 1972; Bennett & Fine, 1977; Sidwell, 1982). Sidwell considered complexity in building process in terms of: the initial complexity of the problems posed by the client in the project brief, the complexity of the solution to the problems provided by the design team and the complexity of the production and assemble operation required to implement the design by the contractor. All of these will affect the organisation and management decisions throughout the project duration from inception to completion and any changes will have an impact on performance.

3.4.2.5 Project location

Construction projects are constructed on different locations which influence their design, organisational structure and construction. The nature and condition of the site will influence other characteristics such as: the type of development, size, functional uses of the building, etc. Furthermore the level of soil investigation and the comprehensive nature of the information on the site and its environment available before the project is designed will also be relevant.

3.4.3 Project Organisational Factors

The organisation of the construction process is dynamic in nature and each project has unique characteristics. Each project will generate a different type of contract strategy and organisational structure as well as style of management. The influence of the project organisation factor can be determined by the measurement of the following variables: organisation strategy; type of contract; method of tendering; interdependence of tasks; and availability and access to information.

3.4.3.1 Organisation strategy

Individual members of the project team contribute a particular expertise to the project and are generally concerned with a discrete functional part of the process (Sidwell, 1982). The method of organisation of the building process reflects the amalgamation of specialists from different disciplines with different objectives. These differences in the objectives of team members will create problems of co-ordination and communication.

The method of organisation and management adopted to resolve the problem will have an effect on variations in terms of number and value of variations ordered, agreement of their cost/value and if disputes arise how they are resolved; all of these will have a profound influence on the project performance.

3.4.3.2 Type of contract

One of the basic requirements for the delivery of any construction project is the creation of an effective mechanism for bringing together a wide range of different professions(Nahapiet and Nahapiet, 1985). A key decision is deciding on which mechanism to use to manage these inter-organisational relationships and how to allocate both the risks and responsibilities to each organisation. The contractual arrangement provide such a mechanism. The various types of contractual methods have been discussed and analysed by many researchers (e.g. Nahapiet & Nahapiet, 1985; Naoum & Langford, 1987; Davidson & Mohsini, 1987). The influence of this variable on the number and magnitude of variations on the project will depend on inter-relationship and inter-dependence of the parties.

3.4.3.3 Management of Design

It is believed in the construction industry that quality is produced when the designer is allowed sufficient time in his search for the best solution to meet the project objectives (NEDO, 1976). However, this position is impracticable to adopt in practice, variations such as, additions, omissions and substitutions, due to design changes becomes inevitable. The number and magnitude of these variations depend on the contractual arrangement chosen, whether it is compatible with the timing of design process (Hibberd, 1986). Some contractual arrangements accommodate design changes more readily than others because design is expected to continue after the contract is made. Nevertheless, changes of this nature could have a severe impact on the design and construction management process.

3.4.3.4 Tendering procedures

Construction contracts are awarded using different tendering procedures. Because of its effect on performance, the selection of the tendering procedure has been the subject of research over several years, more recently by Holt et al (1994). The latter authors examined current tendering selection methods and identified performance factors influencing contractor selection by client organisations. Jahren and Ashe (1990) measured the influence of tendering procedures on cost overruns and examined and analysed differences in client estimates and the estimate of the selected contractor; they concluded that the difference between the two estimates would influence the magnitude of variations on the project.

3.4.3.5 Team relationship

The relationship of the construction team is another important factor. This factor is closely related to the outcome of variation orders during the construction stage of the project (Langford et al, 1986). It will influence both the timing and treatment of the variation orders and the negotiation of their cost. If there is a close working relationship between the client/contractor team then many of the variations which could lead to claims and disputes can be reduced if not eliminated.

3.4.3.6 Interdependence of tasks

Interdependence of tasks refers to the extent to which two or more organisations depend upon one another for assistance, information or other co-ordinative acts in the performance of their respective tasks (Mohsini & Davidson, 1992). This is an important organisational factor, especially in an organisational setting such as a construction project where different professional organisations depends on each other. Crichton (1967) associated the organisational inter-dependence of the building industry with a high probability of conflict. Inter-dependence is also seen as the root cause of organisational breakdown and lower project performances in the building industry. It has been found that the higher the degree of the project organisation inter-dependence of tasks, the greater the chances of conflict which will influence the project performance(Mohsini & Davidson, 1992).

3.4.3.7 Availability and access to information

In any multi-organisation setting, such as in a construction project, any obstacle to the inter-organisational communication process will affect the organisation performance. This is very often the case in construction projects where decision making involving several independent organisations relies on the exchange of information and co-operation between all the organisations. Any breakdown in the transfer of information will result in a significant impact on the project performance. Blocking or delaying of access to the available information can give rise to what Pondy (1967) described as 'dysfunctional conflicts'. If vital information is required, especially in performing a task which is interdependent and sequential to performance of other tasks, lack of access or delay in availability of information can have a significant effect on the project performance.

3.4.4 The Environmental Factors

The term 'environment' describes all external influences on the construction process (Sidwell, 1982). Williams et al (1989) suggested that ' an organisation is embedded in social, political, legislative, economic and technical systems.... which influence the strategy of the organisation and the structural systems and technology that are adopted'. A construction project is thus temporarily subject to environmental influences. However, in order to appreciate the environmental factors which influence construction projects, it necessary to visualise and understand the characteristics and the role of construction industry within the built environment and the economy in general.

Hillebrandt (1984) in the analysis of the construction industry in relation to the economy, states that "the construction industry has characteristics that separately are shared by other industries but in combination appear in construction alone". She went further to argue that the construction industry, through its products, has a greater effect on the environment than any other industry. However, the industry in its role in the economy, as a regulator, is affected and influenced by the environment. The effect and the role of construction in the economy is outside the scope of this paper, the subject is adequately dealt with by many experts on the subject (Ball, 1980; Hillebrandt, 1984; Briscoe, 1988).

The environmental factors will influence the project organisation structure and management as well as the project performance as a whole. Those environmental factors were identified by Hughes (1989). Factors identified included the following:

3.4.4.1 Social

This describes the social environment within which the project is being built. Society is demanding increased comfort and wider variety of accommodations such as, schools, hospitals, factories, houses, offices. Changes in the social environment whether through taste in the society or social legislature or technological changes, after the contract is made may required changes, in design, methods of construction, quantity or quality. In practice the level of these changes may not be known until the construction activities have started on site which may have a severe effect on the project cost and time.

3.4.4.2 Political

This is concerned with government policy and the effects of political decisions on the project. These decisions may affect the construction technique and/or the method of work which may demand changes in design or components of the project, resulting in the instruction of a variation.

3.4.4.3 Economic

This includes the general level of economic activity as well as the economic resources available to do the work. Changes in the economy after the construction work commences on site may lead to variation, for example changes in consumer demand may lead to a smaller/cheaper materials or component being available, this changes will require variation to be issued.

3.4.4.4 Cultural

This describes society's acceptance or tolerance of certain modes of behaviour. It covers such phenomena as 'pressure group or campaigner'. It can have a great effect upon the type of materials or components to be used as well as industrial relations within a project organisation.

3.4.4.5 Technological

This aspect relates to the technology which is available to do the work, both in terms of design and construction work. The major influence of this factor will be reflected in the complexity of the project in terms of the client requirements, the design solutions and the construction techniques, as discussed earlier.

3.5 Construction Management Responses To Variations

Variations often bring to mind the worst image of a construction project (CII, 1986). Cost and time overruns, low productivity, disputes and claims, litigation, have all, at one time been associated with variation.

The inevitability of variations have always taxed the ingenuity and skill of construction project management. The ability to plan for and control variations and problems associated with them, over the years, have marked the demarcation between successful and unsuccessful projects (Barrie, 1981). Proper management of variations on construction projects is no doubt among the most challenging tasks facing the project managers today.

It is reasonably well understood that most of the decisions affecting the incidences or needs for variations on construction projects are taken during the planning and design stage of the project (Barnes, 1988). There is general agreement that variations need to be planned for well in advance and controlled through to the completion stage of the project.

There are several factors, as already discussed above, mitigating events or circumstances leading to incidences of variations on construction projects, some of which can be avoided. Thus, avoidance of variation can often in an extreme situation means abandonment of the project all together. However, some variations can be foreseen or elective in nature to be considered avoidable, for example, substitution of material or component. In principle, the originally specified material or component was suitable but, a substitution may be made to reduce cost, improve performance, or for any other reasons.

Variations will, without doubt, continue to occur but they should be confined to matters which could not have been reasonably foreseen by the project management prior to the contract being offered to tender. Whether foreseeable or not, the construction management responses to variations generally involve advanced planning and control measures aimed to reduce or minimise variations and their impact. The management strategic measures are:

- avoidance or reduction measures
- contingency measure, and
- contractual strategic measure

The first two of these project management strategic measures are part of the planning process for eventual occurrence of variations at later stage of the project. While the contractual strategic measure is part of the project control framework aimed at containing variations and their effects during the construction stage.

3.5.1 Avoidance/reduction strategy

Exhortation to the client not to change his mind and request for changes or to designers to complete the design are seldom effective (Barnes, 1988). However, there are number of strategic measures used to avoid or reduce the number and magnitude of variations on construction projects (Worby et al, 1985; Barnes, 1988; Senior, 1990; Chan and Yeong, 1995). Those reduction strategic measures consider in practice include the following (Chan and Yeong, 1995):

- clear and thorough project brief
- comprehensive site investigation
- thorough detailing of design
- award the tender to the right and competent contractor
- good communication and co-operation between the project team
- retention or containment measure

Clear and thorough project brief

The importance of the project brief in the early stage of the construction project is often overlooked. A poorly prepared project brief is a potential causes of variations and project performance later. Barnes (1988) pointed out that many unneccessary variations arise because the project team allowed the client to leave the briefing decisions untaken or unclear until the very late stage. A systematic interrogation of the client during briefing would help to ensure minimal changes to the design at a later stage of the project.

Comprehensive site investigation

Construction clients often failed to appreciate the importance of detailed site investigations, sometimes, they consider the time and cost for them to be wasteful as they produce no visible benefits (Chan and Yeong, 1995). The designers, in an effort to please their clients, often resort to reducing the amount of investigation work and choose to base their design on inference or guess work. This attitude quite often results in large number of variations during the construction stage of the project when the site turns out to be different from what is expected. Comprehensive site investigation would reduce the magnitude of variations (Worby et al, 1985).

Thorough design detail

For contracts based on drawings and specifications, the design should be thoroughly developed before tender to avoid variations at a later stage of the project. Hibberd (1980) found that inadequate consideration of design and design errors due to insufficient design time, accounted for majority of variations on building projects in U.K. Hence, clients should allow sufficient time for designers to produce the design and specification. Even when design and construction are overlapped, the need for more thorough detailing of design is important for control of variations.

Awarding the tender to the right contractor

The selection of contractor from through an open competitive tendering is usually based on price, where the lowest tender is selected. Often, this selection procedure has proved to be more costly rather than effective because, most often, the contractor put in a low bid to win the contract and rely on variations and claims to compensate for the low price. Bromilow (1971) found that the consequence of awarding the tender to lowest bidder can far outweigh the relatively small difference between the accepted and next higher tender. In a similar study in U.K. by NEDO (1976), concluded that there was a general consensus that the cost of an unsatisfactory contractor can be far greater than any saving by selecting of lowest tender. Pre-qualification of tenderers and selective tendering may be a better alternative to open competitive tendering to ensure awarding the contract to the right compotent contractor.

Good communication and co-operation between the project team

Higgin and Jessop (1965) found that the main factor for difficulties in communication is the nature of the relationship between the project participants. Poor communication, co-operation and relationship between the team often results in claims and disputes as well as delay in their settlement. If the relationships are good, variations will be dealt with by informal communication resulting in immediate action followed later by the necessary formal documents otherwise formal procedures will be adhered to resulting in delay and disruption which often end in disputes and claims (Langford et al, 1986).

Retention or containment response strategy

The construction management retention or containment of variations as means of control is basically to accept and provide for them. The goal of retention strategic response is to minimise the total cost of variations through contingency and contract condition (CII, 1993).

3.5.2 Contingency measure

The common project management measure taken as part of planning process for eventual occurrence of variations is to include a contingency amount in the estimated project cost (Hamburger, 1992b). The contingency allows the project management to act quickly and decisively when the need for variations occur and to mitigate their effects.

The contingency provision measure is based on the philosophy that variations cost can be predicted in advance (Hamburger, 1992a). The contingency amount, however, is arbitrarily set by a rule of thumb based on the judgement and experience of the project manager (or cost consultant). Thus most project managers can readily identify the potential probability of variation incidences on a project but, this approach, over the years, has been proved to be ineffective and overly simplistic (Yeo, 1992).

There are some factors that can be determined, prior to the commencement of construction, that are early warning signs of future variations in a project which the present approach failed to consider in setting the contingence amount (Ranasinghe, 1994a). Other weaknesses of this conventional approach has been highlighted by several research studies (Perry, 1986; CII, 1986, 1992; Yeo, 1990; Ranasinghe, 1994a, 1994b).

The key to an effective method of determining a contingency is objectivity (Hamburger, 1992b). Contingency should be determined with a realistic and justifiable input decision making process rather than preconceived agenda in mind.

3.5.3 Contractual strategic measure

Both avoidable and unavoidable variations have to be controlled on construction projects. The project management control measure for variations is through the conditions of contract which contained the variation clause(s), encompassing the procedure for ordering, measurement, valuation and payment for variations. The conditions of contract do not merely contain the variation clause, but also recognise the contractor's right to compensation for the varied work and appropriate extension of time, and provide the client with indemnity against loss due to variations caused by unforeseen events (eg. Inclement weather).

3.6 Project Performance and Variations

The success of a construction project can be identified in different ways. To the client a successful performance might be completion of the building on time and within budget. While for the professional involved with the project, successful performance might means a satisfied client and a trouble free project. The contractor will also be interested in enhancing his reputation along with an adequate financial return.

The concept of successful performances means different things to individual members of the project team and they will be valued in different ways. However, construction project performance is generally measured in terms of the total cost and time over/under-run of the project. The majority of building projects finished above budget as a result of additional or extra work and /or design changes (Bresnen & Haslam, 1992). The majority of those changes are ordered or approved by the client. For measuring project performance, Bromilow & Henderson (1971) proposed models of number and frequency of variations on a project as measure of the project performance. The development of similar standard models for different types of buildings against which the clients can compare the performance of their projects is suggested.

3.7 SUMMARY

There is no doubt that variations are the major sources of delays and disruptions on construction site. The majority of variations on construction are generated by the client and the designer. Thus, changes during construction works are inevitable and they must be accommodated within the tendered construction program if possible, otherwise an extension of time with costs will be inevitable. Even a completely planned job will generate variations because of changes in technology, performance requirements, or human error during the time span of its construction.

Both the client and designer have been identified as the prolific sources of variations on construction projects. The majority of variations generated were undoubtedly made to save money for already generated or contemplated variations in an attempt to keep the project within the budget.

Many research studies have proposed factors which were identified to influence the magnitude and frequency of incidence of variations on construction projects. These factors may be considered as the context within which variations affect project performances.

Management of variations generally involves measures taken to avoid or minimise the magnitude of variations and their impact. Variations are planed for in advance through the contingency provision, and control through the variation clauses in the condition of contract for the project.

The problems most often encountered with variations (or change orders) revolve around the negotiation of the cost of varied works. The employer often underestimates both the extent and the cost consequence of variations. Failure to reach a mutual understanding on these matters in post-construction negotiations are often due to lack of adequate contingency provision making negotiation difficult.

The management of variations can be enhanced if the contingency provision is realistic and adequate. The present conventional approach uses to set the contingency needs to be improved. However, any improvement must take into consideration the mitigated effects of these factors influencing the magnitude and frequency of variations. This method is demonstrated clearly in chapter 8.

CHAPTER FOUR

ARTIFICIAL NEURAL NETWORKS THEORETICAL DEVELOPMENT AND APPLICATIONS

4.1 Introduction

The preceding chapter reviewed the problem of variations and the project management control bearing in mind their inevitability on construction projects. As evidenced from the review, forecasting of adequate contingency is an important part of the project management control framework. Large variances in the actual cost of variations and the contingency allowance in the budget will impact the project total cost hence the project performance in terms of cost to the client.

As outlined in the introduction chapter, the aim of this research is to develop an alternative approach to forecasting the contingency amount for variations to be added to the project estimated cost. To achieve this objective, the principal modelling technique used is artificial neural networks system. Artificial neural networks, as a modelling tool, is a novel technique that is recently gaining popularity in their application in construction management research. To that end, this chapter reviews the theoretical concepts of artificial neural networks and their previous applications in construction identifying other areas of construction management that can benefit from the capabilities of the technique.

4.2 Reasons for Using ANN

Contingency allowances for variations included in the project cost/budget estimate are arbitrarily set based on experience and judgement of the project manager or cost consultant (Yeo, 1990; Ranasinghe, 1994). This approach has been criticised and proved to be inconsistent and unrealistic due to a number of reasons. One of those reasons is that there is no formal procedure or mechanism that shows how the estimator's past experience is related to the project to justify how the contingency amount was derived. Therefore, the approach does not guarantee a consistent estimate.

As reviewed in the last chapter, the magnitude of variations on construction projects are influenced by a number of factors. These factors and their influences need to be taken into consideration in setting any realistic contingency. A formal approach therefore, is to record or measure the relevant factors on various projects, process quantitatively, to establish the relationships between variations and the relevant factors. The established relationships can be modelled and used to forecast the contingency for the new project.

There are several modelling techniques that can be employed to achieve this objective. In construction, many mathematical models have been developed and applied to forecasting of the project cost estimates (Raftery, 1984). However, the application of those models has to be based on some pre-assumptions (e.g. linearity, normality, etc) in line with the modelling technique, which limits their application in some situations. Artificial neural networks as a modelling technique, as opposed to mathematical or statistical technique such as multiple regression, are suitable for those complex situations.

Artificial neural networks as analogy to human brain requires no assumption about relationships between variables because of their adaptability owing to their ability to learning both linear and non-linear pattern in a data. This important property makes neural networks, compared to methods such as multiple regression and discriminant analysis, suitable for the research where there is very limited previous research studies.

The advantage of using the technique however is two-fold; first, a broad range of factors influencing the magnitude of variations on construction projects can be incorporated as inputs variables. The factors, as the model parameters, can therefore be described in formal and logical terms that are familiar to the project management team. Finally, the contributing influences of each factor can be easily demonstrated and justified.

4.3 Artificial Neural Network (ANN): Origin and Concept

Artificial neural networks are mathematical models intended to imitate the functions of the human brain, using some its basic structures. They exploit and attempt to model the brain learning, thinking, storage, and retrieval of information, as well as associative recognition properties that are believed to exist in the human brain. The primary intent of artificial neural networks is to reproduce human information processing tasks such as speech, vision, knowledge processing, and motor control (Murza, 1993). Additionally, they have been used for data compression, pattern matching, system modelling, and functional approximation.

Thus, the field of artificial neural networks originated in 1940s with the work of McCullock and Pitts, it was not until the late 1970s and beginning of 1980s that it attracted substantial attention. This attention was generated primarily due to the works of Anderson (1977), Kohonen (1977), Grossberg (1980), Hopfield (1982) and Rumelhart and McClelland (1986). Hopfield (1982) demonstrated that artificial neural network could be trained as an associative memory using Hebb's postulate for connection weight modification. Kohonen (1982) also proposed an artificial neural network based on self-organisation. His idea was to make use of the fact that the sensory signals are represented as two-dimensional images/maps in the mammalian cortex. This idea resulted in formulation of a model with a self-organising mechanism, which used a neighbourhood function to define the area in which to cluster similar input signals.

4.4 Neural Network Characteristics

This wealth of knowledge and the breadth of interest in artificial neural networks has, in recent years, increased the use of the technique in many research areas including construction management, As a result, the range of alternative artificial neural network modelling systems is immense and growing rapidly. However, each system has its own characteristics, which determine its suitability for solving certain class of problems. A useful means of putting the systems in perspective is to classify them according to four principal characteristics: data format and interpretation; the network architecture; mode of operation; and the training method (Flood and Kartam, 1994b). Each of these characteristics is discussed in turn.

4.4.1 Data format and interpretation

The way data is represented and input in to an artificial neural network has a major impact on the training of the network and on the performance of the resulting model. The network ability to discriminate, its effectiveness in generalisation, and the amount of computation and time it requires for learning are all greatly influenced by the data format and representation (Smith, 1993).

Artificial neural network data is usually either discrete/class or continuous, though sometimes it may be symbolic (that is nonnumeric in form) or a mixture of all these types. The method of representing and interpreting data in a given situation is determined primarily by the problem to be solved and the type of network adopted (Flood and Kartam, 1994b). An input variable used to indicate sizes ("small", "medium", and "large"), for example, can be represented in many ways, by (1) a single valued input with values 1, 2, and 3 representing the three size range; (2) three binary inputs with values 1 or 0 to indicate yes or no for the size range.

Network data is, generally, normalised before it is input into network P.Es. The normalisation so that the range of values at each input or output P.Es are in the range 0 to 1 is done using the formula:

$$Normalisedvalue = \frac{originalvalue - \min imumvalue}{\max imumvalue - \min imumvalue}$$

The normalisation of the data before it is presented to the network provides a balance in the rate of learning with respect to each input and output variables relationships (Flood and Kartam, 1994a).

4.4.2 Network structure

The artificial neural networks, in terms of structure/architecture, are composed of a number of processing elements (PEs) that communicate through a set of interconnections (Moselhi et al, 1992). There is several innovative artificial neural network architecture (paradigms) which has been developed over the years to provide distinct capabilities. The most common network architecture is the multilayer perceptrons (MLP) network. A typical simple MLP network is shown in Figure 4.1. It consists of a number of layers (three in this case), the input, hidden and output layers. The layers are connected in a way that output from the PEs in one layer are fed via the weighted connections as inputs of the PEs in the next layer.

MLP network has been proven to have adequate capabilities to solve most problems (Moselhi et al, 1992; Flood and Kartam, 1994a, 1994b). However, if a problem is particularly complicated, it may be broken down into a number of parts, each of which is then solved separately by its own network module (Boussabaine and Cheetham, 1995). The nature of the problem to model, generally, defines the structure of the network.

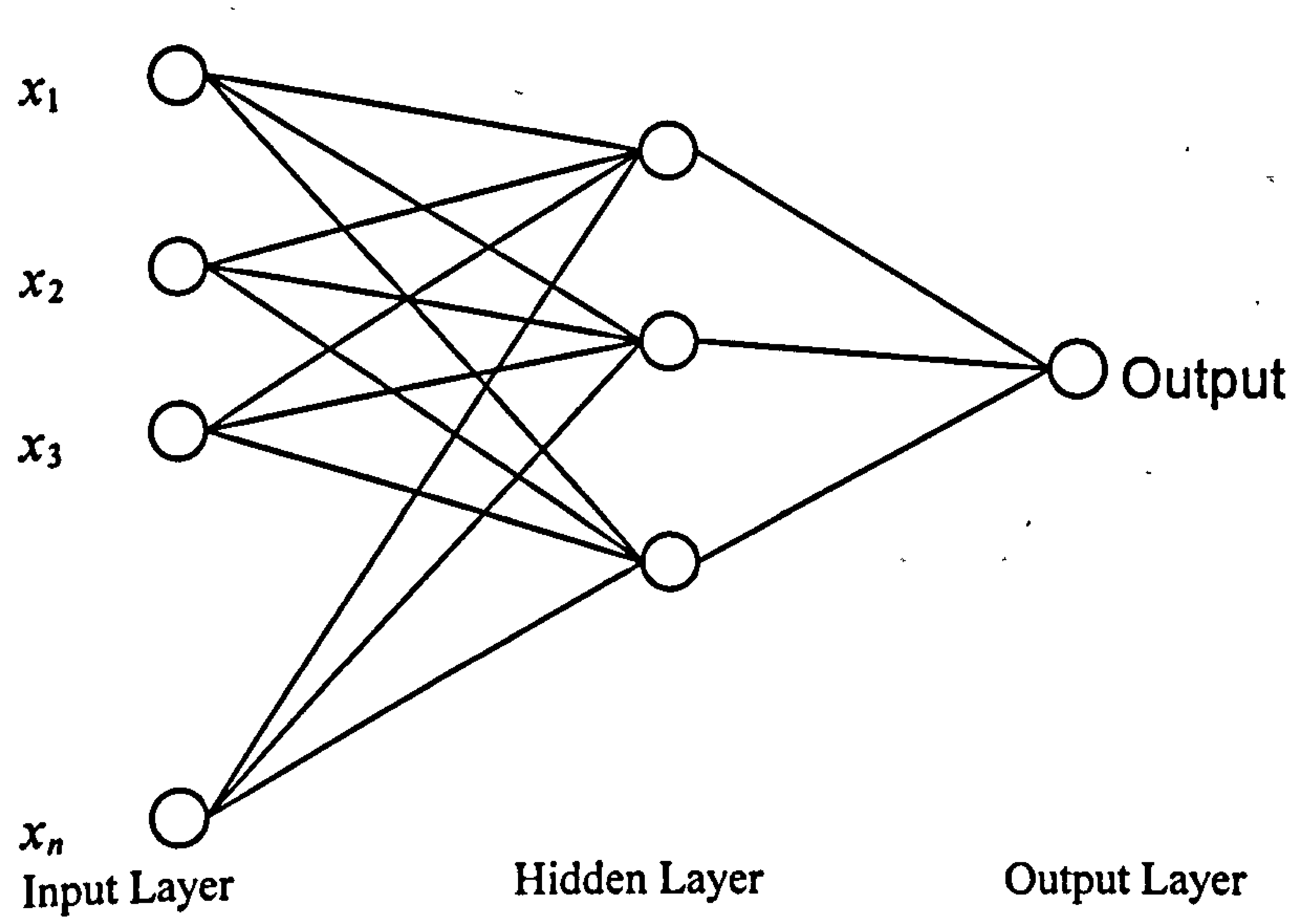


Fig. 4.1: Simple MLP Network

Another network paradigm is *counterpropagation* (Hecht-Nielsen, 1987, 1988). A simplified feedforward counterpropagation network is shown in Figure 4.2 (Wasserman, 1989). Counterpropagation network uses the same principles as that of multilayer perceptron, however, the difference lie in the processing done by Kohonen and Grossberg processing elements (see appendix 4 for description and mathematics of both the 'kohonen' and 'Grosberg' layers). However, the results of counterpropagation are not as accurate that of a MLP, however, due to its improved learning speed, it could be used for rapid prototyping or when high accuracy is not mandated. Also, its capability of generating a function and its inverse can envision many application (Wasserman, 1989).

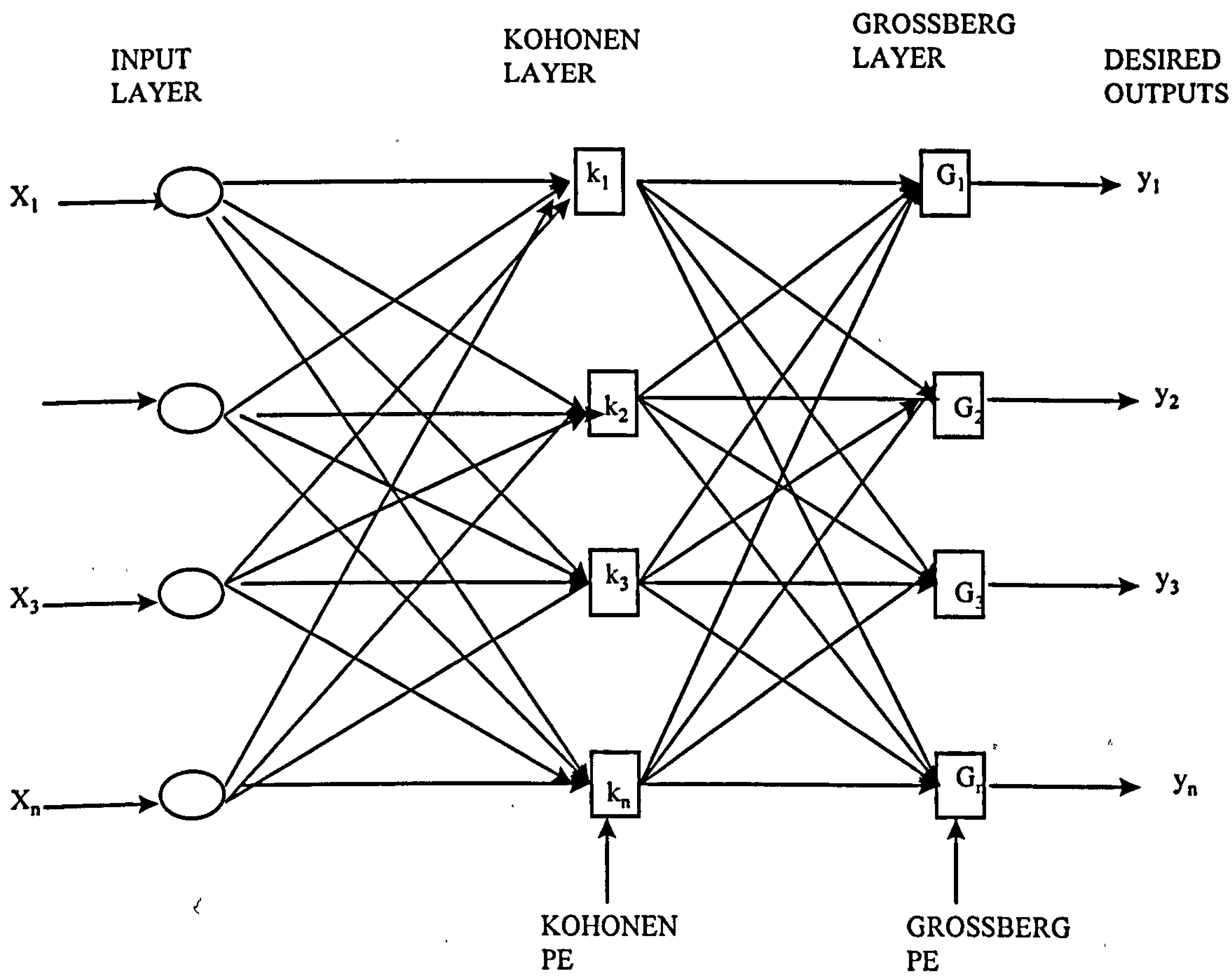


Fig. 4.2: A Simple Counterpropagation Network (Wasserman, 1989)

Hopfield is another artificial neural network paradigm. Hopfield network, unlike the MLP and counterpropagation networks, is recurrent network, that is, there is no feedback from the output of the networks to their input. Because of the feedback paths from the outputs back to the inputs, the response of Hopfield networks is dynamic and applicable in situations where inputs for the same pattern change state. A typical Hopfield network is shown in Figure 4.3. Another advantage of this network is its increased learning speed and powerful associative memory capabilities. Once the network is trained, it can produce the desired output, even if the input is partially incorrect or incomplete.

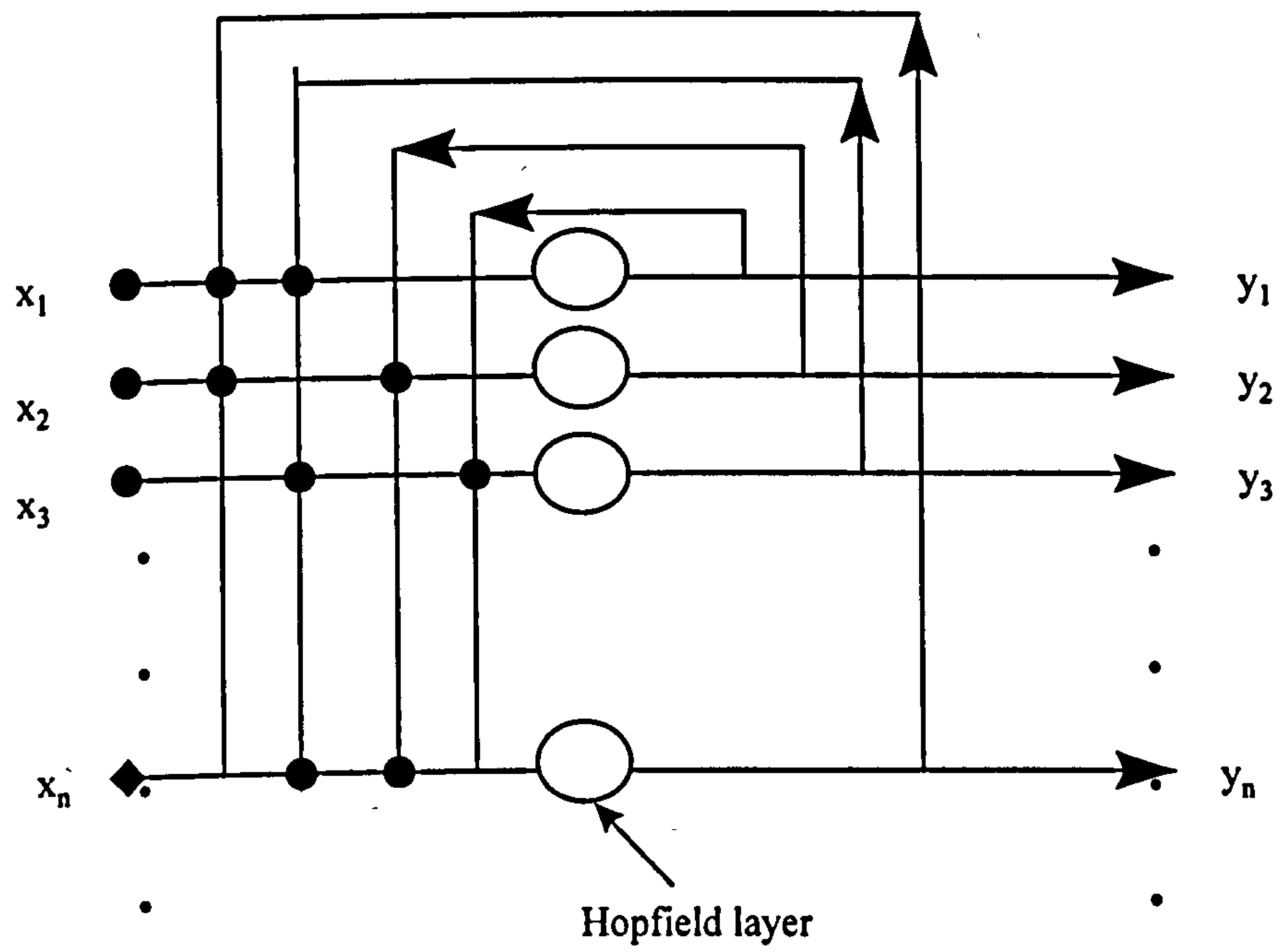


Fig. 4.3: A Simplified Hopfield Network (Wasserman, 1989)

The main problem with Hopfield network is that it has tendency to settle into local minima by constant energy minimisation (Fu, 1994). This phenomenon, thus desirable for association but it is undesirable for optimisation or constraint satisfaction. The problem is solved by another network structure called the *Boltzmann machine*, in which the processing elements change state in a statistical rather than a deterministic fashion. By adding some randomness to the process of energy minimisation, the local minima problem is avoided, so when the network move toward a local minima, it has a chance to escape.

Bidirectional associative memory (BAM) network is another alternative network structure. BAM networks are heteroassociative, that is, they accept an input vector on one set of processing elements and produce a related, but different, output vector on another set. Like Hopfield network, BAM networks are capable of generalisation, producing correct outputs despite corrupted inputs. A typical BAM network is shown in Figure 4.4. As shown in the figure, the network has a recurrent two-layer structure in which the backward weight (from the output toward the input) is the transposed of the forward weight (from input to output).

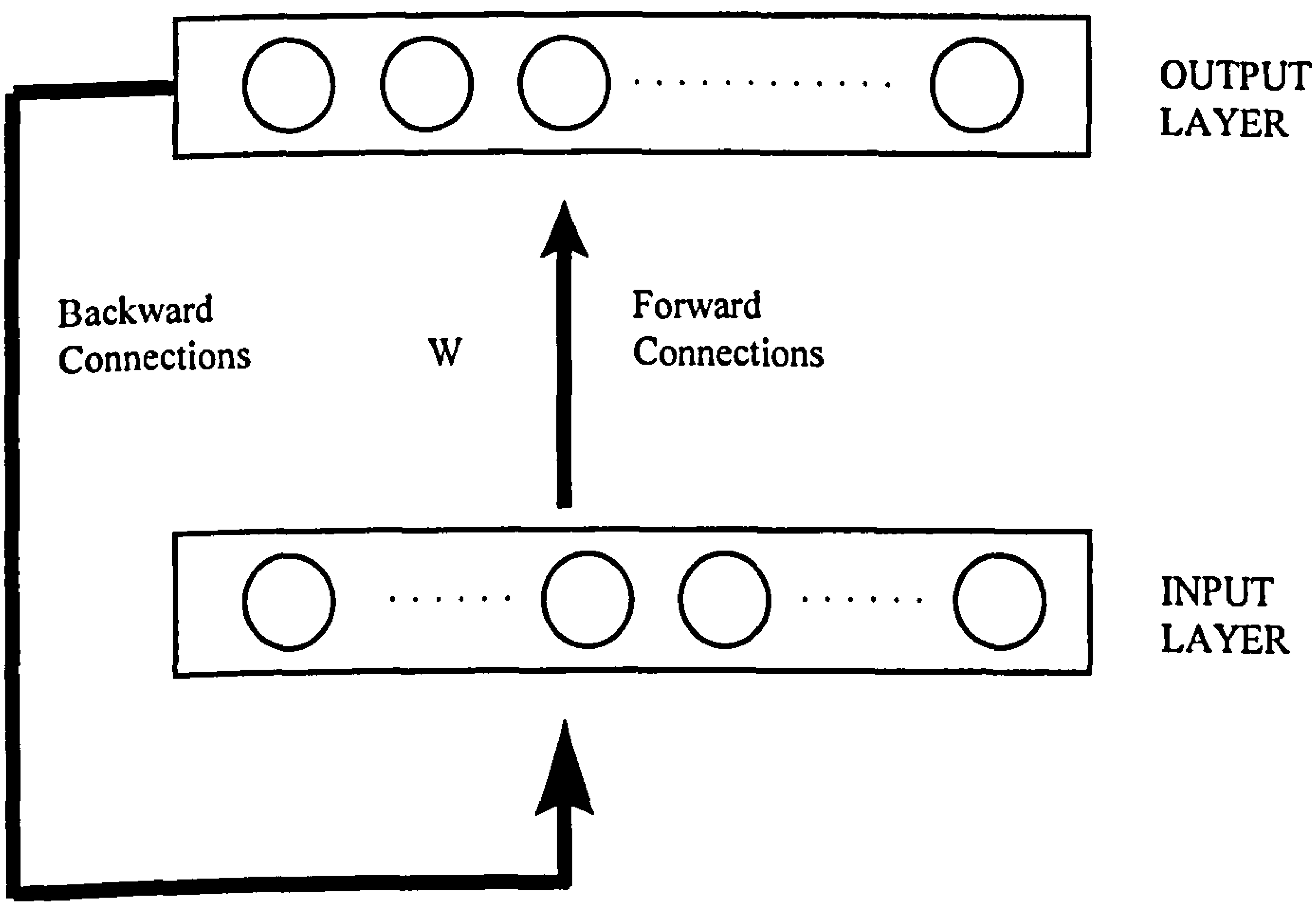


Fig. 4.4: A Bidirectional Associative Memory Network (Fu, 1994)

Adaptive resonance theory (ART) networks are useful networks for pattern clustering, classification and recognition. Table 4.1 summarised the structural characteristics of this network with the others along with their advantages and limitations.

4.4.3 Mode of operation

Artificial neural networks as opposed to conventional computer programs which serially execute a set of programmed instruction, are trained and controlled based on the structure of the connections among the P.E.s and the training method adopted (Moselhi et al, 1992). Each P.E can be considered as simple microprocessor that receives signals, performs some form of processing (i.e. summation) on the signal and places the result through an activation function (often sigmoid function) and transmits an output signal. The summation and transfer function of typical PE are demonstrated in Figure 4.2. The output path of a PE can be connected to the input of one or many other PE in the next layer. The strength of the output signals to the other PEs is determined by the connection weight. The connection weight modifies the output signal on each path connecting one PE to another allowing some path to become stronger and others to be weaker or even zero (Fu, 1993).

Developer	Training time	Number of layers	Transfer function	Network structure (paradigm)	Advantages	Limitations	Uses
Rosenblatt 1961, and Rumelhart et al. 1986	Medium	2 or more	Sigmoid	MLP	■ simple ■ powerful and accurate association ■ suitable for static environment (input does not change with time)	■ limited capability ■ (1) could be trapped in local minima ■ (2) no incremental learning	High
Hecht-Nielson 1987	Medium	2 or 3	Kohonen and sigmoid	Counterpropagation	■ good for rapid prototyping ■ (b) above ■ can generate a function and its inverse ■ has powerful probabilistic capabilities	■ not as accurate as backpropagation ■ (1) and (2) above	High
Hopfield 1982	Fast	1	Hard limiting	Hopfield	■ © provide dynamic performance ■ (d) sufficiently responds to noisy, incomplete or unseen inputs ■ (e) can be used for optimisation	■ stability not guaranteed ■ (3) memory limitation ■ difficult to formalise training method ■ (1) and (2) above	High
Kosko 1987	Fast	1	Clamped linear	BAM	■ ©, (d), and (e) above ■ easier and systematic training methodology than Hopfield ■ more simple and faster ■ no stability problem ■ provide adaptive performance	- (1), (2) and (3) above	Low
Hinton and Sejnowski 1986	Slow	2 or more	Varies	Boltzmann machine	■ alleviate local minima problem ■ use probabilistic training method	■ very slow ■ (2) above	High
Carpenter and Grossberg 1987	Fast	1	Sigmoid	ART	■ facilitate learning new examples without destroying previous experience		High

Table 4.1: Artificial neural networks paradigms (Bailey and Thompson, 1990a)

4.4.4 Training methods

Training a neural network is the iterative process of adjusting the network connection weights, in response to a number of examples (cases) being presented at the input PEs for several times (training iterations). The task is to arrive at a unique set of weights needed to calculate outputs that are very close to the desired outputs (i.e. within a specified error limit), for all the cases used in training. After training, the values of the weights represent the neural network state of knowledge. The trained network can then be used by applying a set of inputs, and the network will produce outputs that are satisfactorily close to the desire set of outputs. This process involved modification of the network weight matrix in order to improve the network performance and is generally referred to as "learning". Learning process used to train a network will dependent on the method of training adopted. Generally, there are two types of training methods: supervised, and unsupervised training methods.

4.4.4.1 Supervised method

Supervised training method is the most commonly used and it requires historical data with examples of both inputs and outputs. The supervised training is based on the network system trying to predict outcomes for known examples, that is the network is trained with error correction learning which means that the desired response for the system must be known(Lippman, 1987). The network compares its predictions to the target or desired outcomes and "learn" from its mistakes. The process start as inputs to the input layer PEs, the PEs passes the inputs along to the next PEs. As inputs are passed along, the weighting is applied and when the inputs reach the next PE, the weightings are summed and either intensified or weakened. This process continues until the data reach the output layer where the network predicts an outcome. The predicted output is compared to the actual output for that case and if the predicted output is equal to the actual output, no change is made to the connection weights. But, if the predicted output is higher or lower than the actual output, the error (differences) is back propagated through the system and the weights are adjusted accordingly.

The learning process in supervised training requires three basic decisions that need to be made: choice of the error criterion, how the error is propagated through the network, and what constraints (static or across time) are imposes on the network output (Fu, 1994). The first issue is related to the formula (the cost function) that computes the error. The second aspect is associated with the mechanisms that modify the network parameters in an automated fashion (the learning algorithm). The third aspect is associated with how the network output versus the desired signal is constrained.

Cost function

In supervised training, the network learns to match its outputs to a given pattern. The key feature in this process is the "cost function", which measures the difference or error between the actual outputs during training and the correct outputs for each training case. After all training cases have been run, the cost function is calculated for the training set by summing the final cost functions of each training cases, thus providing a measure of the overall performance of the network (DTI, 1994).

There are several ways to compute the cost function. The most commonly used is the mean square error norms (also called l_2 norm), and is defined by

$$E_p = \sum_{i=1}^{m} \sqrt{(y_i - t_i)^2} \qquad (1)$$

Where E_p = the term of the cost function for a given pair of output and desired response

m = the number of output PE

y_i = the actual output of the i^{th} output PE in response to some input pattern

t_i = the desired response of the i^{th} output PE when presented with that input

This function has the effect of reducing the training algorithm's sensitivity to "outliers", that is data that lie unusually far away from the general distribution of the data.

Learning algorithms

Learning algorithm (or rule) is the mechanism used to modify the network parameters. In supervised training, there are a number of learning algorithms used to train an ANN. The most widely used learning algorithm is the "gradient descent learning" (also known as the "standard back propagation") (DTI, 1994). This learning algorithm calculates the direction in *n*-dimensions of the weight changes that will bring about the greatest reduction in the cost function (where n is the number of weights that are to be adjusted). The amount of the adjustment is controlled by two control parameters:

- the "learning rate" which define rate of progress

The principle of gradient descent learning is very simple. The idea is to define a measure of the overall performance of the system (cost function) and finds a way to optimise that performance. The network performance is defined by equation 1 above, the goal then, is to minimise this function by changing the weights of the network in proportion to the partial derivative of the error with respect to the weights (Rumelhart et al, 1994). Each weight is update by a constant proportion of the partial derivative of the error function (cost function) with respect to that weight (White, 1989) i.e.

$$\theta_i = \theta_{i-1} + \delta\,\Delta f\left(x_i, \theta_{i-1}\right)\left(y_i - f\left(x_i, \theta_{i-1}\right)\right)$$

Where δ is the learning rate, y_i is the target, θ_i is a random set of small initial weights, and Δf is the gradient (vector containing partial derivatives) of f with respect to the weight θ is calculated using the formula:

$$\Delta f = \frac{\partial E}{\partial y_i}\frac{\partial y_i}{\partial w_{ij}}$$

where the E is the total absolute error of the network. This algorithm changes each weight of the network based on its localised portion of the input signal and its localised portion of the error. The drawback of the algorithm is that the search for the optimal weight values can get caught in local minima, that is, the network thinks it has arrived at the best possible set of weights even though there are other solutions that are better. Another problem is that it is slow to converge, and the learning rates must be set heuristically (Lippmann, 1987).

There are refinements of the gradient descent algorithm that can improve the training time and some of the drawbacks. Scme of the better known improvement is the "delta-bar-delta" and the "quick prop".

The delta-bar-delta uses separate learning rates for each individual weight in the network, and adapts the rates according to the past behaviour of the weights. This method can yield speed improvements of up to three times those achieved by standard back propagation. The quick prop method on the other hand, assesses the learning rate for each weight by making an approximation to the shape of the cost function surface at every step. This method however, is hard to implement and uses a large number of control parameters (DTI, 1994).

4.4.4.2 Unsupervised method

Unsupervised training, unlike supervised method, does not have known answers to train the network but instead creates its own interpretation and validation of the data. By using the correlation of the input, the training method changes the network weights to group the input into 'clusters' such that similar inputs will produce similar network outputs since they will belong to the same cluster (Fu, 1993). The unsupervised method is uses for solving cluster analysis type problems.

Most of ANNs that use the unsupervised training has a very simple structure, layer networks. As there is no 'teacher', the networks are self-organise according to some internal rule in response to the environment. The selection of a learning algorithm, however, will depend on the nature of the data available, and the nature of the problem to solve.

There are a number of learning algorithms use to train unsupervised neural networks. One of the plausible learning algorithms is the 'Hebbian' learning. The idea of this learning is to modify a network weight, proportionally, to the product of the input and the output of the weight, i.e.

$$\Delta w_i = \mu y x_i$$

Where μ is the learning constant, and y the single output of the network. This algorithm implements, iteratively, the idea of correlation between x and y (the input and output of the weight).

One of the problems of Hebbian learning is that the weights may grow without bounds if the input is not properly normalised, and learning never stops. A very effective normalisation was proposed by Oja (NeuroDimension, 1995) i.e.

$$\Delta w_i = \mu y(x_i - y w_i)$$

This normalisation optimised the algorithm and can be extended to M multiple outputs, yielding:

$$\Delta w_{ij} = \mu y_i (x_i - \sum_{k=1} y_i w_{kj})$$

where

$$y_i = \sum_j w_{ij} x_j \qquad i = 1, \ldots . M$$

Another unsupervised learning algorithm is "competitive learning" (Wasserman, 1989). This is accomplished by creating inhibitory connections among the output PEs. The idea of competitive learning is that the output PEs competes to be on all the time (winner-take-all). In other word, only one of the output PEs can be active at a given time (called the winner), which is defined as the PE that has the largest summed input. If the weights to each PE are normalised, then this choice takes the winner as the unit closest to the input vector x in the l_l norm sense, i.e.

$$|\vec{w}_{io} - \vec{x}| \leq |\vec{w} - \vec{x}|$$

Where i^o means the winning PE. For the winning PE the weights are update as

$$\Delta w_{ioj} = \mu(x_j - w_{ioj})$$

which displaces the weight vector towards the input pattern.

4.5 Construction Management Applications of ANN

Compared to other research areas, little has been published on the application of artificial neural network to construction management. Its application dated back to early 1990s already covering a range of topics (Boussabaine, 1996). In order to demonstrate the modelling and problem-solving capabilities of Artificial neural networks and their appropriateness for application in the research, previous research application of the technique in construction cost and productivity estimates are reviewed.

Flood (1989) described the development of an ANN based model for optimising the sequencing of construction tasks with the objective of minimising production time. The basic idea behind the research is that when a matrix of times spent by each job at each process is simulated by ANN, the resulting model can produce an optimal job sequence. The testing results of the model proved that ANN produces a valid model of the problem.

Moselhi et al. (1991) reported on development of a trial ANN model for prediction of the optimum mark-up estimation under different bid situations. The model uses as its input the number of typical competitors, the mean of the distribution of the ratio of the competitors' bid prices to the contractor's estimated cost in previous encounters and the standard deviation of the latter distribution. Three bidding strategy models were used to provide the desired network output (optimum mark-up) in response to the different bid situations. The model was able to generalise solutions and captured the probabilistic nature of ten bid situations used in the trial.

Murtaza (1993) in research study of the construction modularization problem, developed an ANN based decision model to support the modularization feasibility decision. The model was developed based on various decision factors such as plant location and characteristics, project risk, labour consideration, environmental and organisational factors, etc. The system is trained using forty cases and the performance of the model is tested on ten independent cases. The validation tests showed that the model decisions were accurate.

Williams (1994) applied artificial neural network modelling technique to construction cost index problem. He developed a three-layer neural network model to predict the changes in construction cost indexes. The system uses as input the recent trends, the prime lending rate, number of housing starts in the month and the month of the year. The developed model produces three outputs: the percentage change in construction cost index one ahead, the percentage change in construction cost index six month ahead and prediction of monthly change greater than 1.5% or less than -0.5%. The output from the ANN model was compared with predictions made by an exponential smoothing and regression models. The author found that both the exponential smoothing and regression models performed better than the ANN model. He concluded that the movement of the cost indexes is a complex problem that cannot be solve accurately by ANN. This findings contradict the advantages claimed for ANNs over statistical modelling techniques (Smith, 1993; Fu, 1994). However, the failure of the model could be attributed to the selection and design of the input data or failure to find an optimum network topology and structure to obtain a suitable model (Boussabaine, 1996).

Chao and Skibniewski (1994) developed two ANN models for estimating excavation capacity based on the job conditions, and estimating excavator efficiency based on the attributes of the operation elements. The training data for the models were generated from desktop excavator model and simulation program. The output of the first ANN model, excavator cycle time, is used as an input to the second model. The outputs of the second model include hourly productivity plus the mean and standard deviation. Thus, the number of the hidden layer and their processing elements was fixed and there was no search for the optimum network parameters, the models' performances demonstrated the potential for applying ANN technique to construction productivity estimation.

Hua (1996) developed an ANN model to predict demand for residential construction in Singapore. The model uses as input twelve economic indicators. To evaluate the performance of the model, a multiple regression (MR) model was developed using the network inputs as the independent variables. In a comparison of the two models, in terms of their forecasting accuracy based on the mean absolute percentage error, ANN model is found to performed far better than MR model. Hua attributed the performance to the network ability to capture the non-linear relationship between the inputs and the output variables automatically without having to specify or make any assumption about the data.

These studies have proposed and demonstrated the applicability of artificial neural networks in construction management. Thus, none of the ANN models reported has been fully developed to be implemented in practice but, the potential of ANNs as tools in construction management is obvious from these studies. Other construction management areas that can benefit from the potential capabilities of the ANNs as modelling technique over the conventional techniques has been identified (Moselhi et al, 1991; Bossabaine, 1996). The identified areas included project cash flow forecast. An ANN can be used to provide assistance to contractors in predicting, updating and managing project cash flow.

Another area identified as suitable for application of ANN is risk analysis. An ANN as tool in risk analysis will assist in decision making in financial investment and in assessing situations where opportunities for alternative contractual arrangements are available in terms of risk and reward allocation.

The decision making regarding the selection and classification of construction material, plant and construction method, can also benefit from the application of ANN. The available information and knowledge about the process of selecting and classifying these resources together with data about the strengths and weaknesses in meeting operational requirements and the general priorities and preference of the industry uses of existing comparable construction technologies could be used to developed a decision making system.

4.6 Summary

The origin and theoretical concept of artificial neural networks has been described with their modelling capabilities. As opposed to conventional modelling techniques, such as multiple regression and discriminant analysis, artificial neural networks process implicit information extracted from historical data in the form of patterns with relative ease without any pre-assumption regarding the nature of the data. Several aspects related to characteristics of various types of network were addressed for purposes of understanding the adaptability of the technique as a research tool.

The recent applications of artificial neural networks to construction related problems were also reviewed. The chapter concluded with identification review of other potential area of construction management research problems that can benefit from the application of the technique.

CHAPTER FIVE

RESEARCH METHODOLOGY

5.1 Introduction

This research study is predicated on the assumptions that, there are number of factors influencing the magnitude of variation incidences on construction projects and given those factors, the magnitude of variations on a project can be predicted. This being so, an overview of the research methodology adopted for the investigation to test these assumptions is discussed in this chapter.

The research starts with the literature review of previous research studies and texts concentrating on the research problem. From the review, the research conceptual model was developed as a framework for the research. The procedures adopted for investigation and testing of the model are discussed with an outline of the method of analysis of the collected data and a test of the research hypotheses. The techniques used to develop the mathematical models and their validations are also discussed.

5.2 Literature Review

An extensive and comprehensive literature review of past research studies reports and text was conducted as the first step of the research focusing on previous works that had been produced in this particular area of construction management and in the project management and performance area in general. The review works are listed in references section of the thesis.

The review indicated that very little research efforts had been direct to this particular problem area of construction. The few research efforts had been focued on source and nature of variations, and no single research had been carried out to examine the factors influencing the sources of variations. The review covered also covered a wide range of issues including the following:

- the structure of the construction industry and management of risk and uncertainty (Ch. 2);
- the source and cause of variations on construction projects with the factors influencing the decisions to order changes, as well as the method used in planning and controlling them (Ch. 3);
- the concept and applications of the artificial neural network modelling technique in construction management (Ch. 4);

The review was followed by brainstorming interviews and discussions with professionals in the industry and academic experts to collate the literature review findings with the industry's professional perception of the problem. The main objective of the literature review was to properly define the research problem and establish the research methodology to be adopted for the investigation.

5.3 Research Model

Social sciences exploit modelling techniques to represent or explain phenomena and relationships in the real world. As a technique, modelling enables the research problem to be visualised and comprehended, and assists in explaining the research approach, communicate ideas, aid understanding and permit prediction through definition, measurement, collection and ordering of research information (Echenique, 1970).

Modelling techniques have been used in construction research studies as far back as 1960s as a framework to visualise and investigate the effectiveness of the construction industry and its production process. Those studies, model the structure of the industry (Higgin & Jessop, 1965; Crichton, 1966), the participants involved and the sequences of production (RIBA, 1967). Others, focus on the structure and organisational interfaces of the construction process (Morris, 1972), decision making and organisation structure (Walker, 1980), and performance of various project organisation forms (Sidwell, 1982; Rowlinson 1986; Naoum, 1989).

These studies have developed various research models based on Cleland and King (1968) 'system analysis approach' to model and investigate construction management problems. Morris (1972) with the aid of Lawrence and Lorschi's work and the RIBA model adopted the system approach to investigate the fragementation problem of construction project development. Focusing on the interfaces between the design and production functions, he identified three main subsystems of construction process as the design, design realisation and construction. He used the model of these subsystems to study the organisational behaviour of project team under various organisation forms.

Walker (1980) also used the system approach to develop a client oriented model of the construction process. He used the linear responsibility analysis technique to investigate decision making and appropriate organisation structure of construction projects. He also identified three main stages of project development, the conception, inception and realisation of the project.

Sidwell (1982) modelled the principal variables present in the construction project management to investigate project performance. In applying the model to 32 case studies, he concluded that project success would depend upon matching client and project characteristics with the appropriate procurement and building team. The model was used by Naoum (1989) to compare performances of traditional contracts with the management contract in the UK.

Given the research aim of improving the understanding of variations as an inevitable part of construction and the collective experiences of these previous research studies, the research model was developed based on the system approach. The system approach according to Cleland and King (1968) illustrates the interreaction and interdependence between the identified factors of the system, suggesting that an action of one factor can cause a reaction on the part of the other factors.

The research model is given in Figure 5.1 shows the seven groups of factors of the construction process. The model in a way differs from previous models discussed above. Thus part of the research main objectives was to identify factors in the construction process influencing the magnitude of variations on construction project. However, it is not the intention of the research to show in definitive terms or otherwise the structure or configuration of a particular factor, instead it determines the relevancy of the influences of the factors on the magnitude of the variations.

Of the seven elements, the first two, that is the client and project characteristics, are seen as primary independent/input factors. To use the model, one would have to start with an assessment of these two elements as they determine the selection of the variables of the three conversion elements, that is the designer characteristics, procurement strategy, tendering procedure and the production, with the objective of minimising the sixth element, variations magnitude. The construction project being a temporary organisation, all the elements would be subject to the project environment variables.

The model is intended to provide a framework for examining the relationship between these factors and the magnitude of variations. However, if the extent of the influences of these factors can be ascertained, they can be used to determine a realistic and manageable contingency as part of the budget for eventual occurrences of variations during the construction of the project.

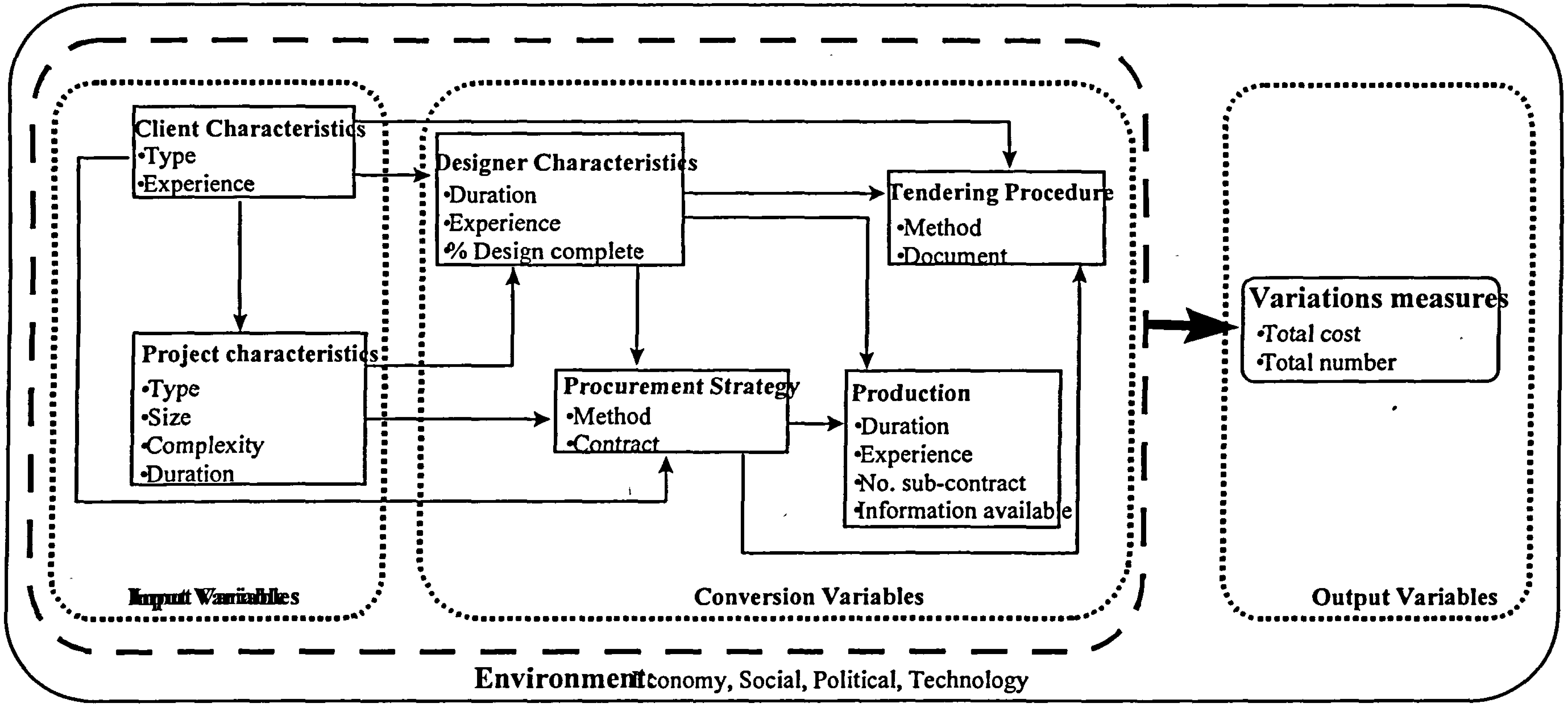


Fig. 5.1: Research Model

5.4 The Research Hypothesis

The research study objectives and the model discussed above has stimulated two principal hypotheses, developed with the overall aim of the research in mind, to be investigated and tested. The hypotheses are:-

1. The magnitude of variations on construction projects is a function of the client characteristics, project characteristics, designer characteristics, procurement strategy, tendering procedure, production and environmental factors.

This first hypothesis lead to the second hypothesis-

2. Given the relevant factors, the magnitude of variations on a construction project can be realistically predicted with a significant accuracy.

5.5 The Questionnaire Design

The design of the questionnaire as the main data collection tool was a multi-step process. The process started with drafting of a list of potential factors that might influence the magnitude of variations. This was obtained from the literature and brainstorming interviews and discussions with professionals on the industry in one hand and the academic experts on the other. The process concluded with the initial version of the questionnaire designed and structured in a manner that will facilitate case analysis of the collected information. Prior to the main study survey, the questionnaire was tested in a pilot study and refined. The final questionnaire used for the survey was divided into three sections; A, B and C.

Section A: Contained questions structured to obtain general information about the responding organisation enabled the classification of responding organisation by activity, turnover and profession.

Section B : This contained questions specifically for a project chosen by the respondent from projects completed by the organisation within the last 5 years and typical of the organisation's activity. The questions were geared to determine the magnitude of variation incidences on the project and the sources and nature of these variations. The questions determined the degree of influence of factors identified as affecting the magnitude of variations.

Section C : The final section of the questionnaire contained questions in referring to the variation clause(s) contained in the condition of contract used.

5.6 The Survey

The sample in the survey was obtained through randomly selected organisations and companies within the construction industry and the industry's client organisations from various sources. The contractors and consulting organisations were selected from:

- New builder contractors file' 1993 and 1994;
- New builder professional file' 1993 and 1994;
- Royal Institute of British Architects 1993/94 list of practices;
- Association of Consulting Engineers' list;
- Royal institution of Chartered Surveyors 1994 list of members;

The client organisations were selected from:

- UK directory of property developers, investors and financier (1993/94);

All of the selected organisations were initially contacted through telephone and letters asking for their assistance stating briefly the research objectives and the proposed approach of the research.

5.6.1 Pilot Survey

The questionnaire was tested on 16 completed building projects. The contractor and consultant organisations provided the information through either an interview using the structured questionnaire with the person in-charge of the project, or by telephone asking for their assistance and co-operation followed by a postal questionnaire which were completed and returned After the data analysis and evaluation of the results, the questionnaire was modified following the discussion of the result with a number of practitioners. The questionnaire was then prepared ready for the major survey.

5.6.2 The Main Study Survey

Of the 375 organisations and companies approached, through telephone and postal correspondences, only 127 expressed their willingness to assist with the research. These organisations were sent copies of the questionnaire with covering letters reminding them again of the purpose of the research. The directors, chief executives or contract managers whom the letter was addressed to in turn asked the appropriate personnel familiar with the chosen project within the organisation to complete the questionnaire. In all data from 45 building projects completed within the last five years were collected and analysed in the study reported in this thesis.

5.7 Method of Analysis

Data collected in the study were analysed using various techniques on a computer with the aid of statistical package for social sciences (SPSS). Considering the quantitative multivariate nature of the research required the uses of several analysis techniques. These techniques were:-

- Relative index ranking technique;
- Correlation analysis;
- Multiple regression analysis;
- Sensitivity analysis
- Neural network modelling;

All of these analysis were carried out on a computer. Each of the techniques is fully explained and applied in the relevant part of the thesis.

5.8 Model Development

The principal modelling technique used to build the predictive model and test the study second hypothesis is the neural network modelling technique. Neural network is a mathematical based computer modelling technique intended to imitate the function of the brain information processing tasks in decision making such as the case in this research. The review of the technique concept and previous applications in construction management research is discussed in chapter 4.

In developing the model, attention as been focussed upon the important influencing factors for optimising and simplifying the model. To evaluate and assess the model performance, the commonly used modelling technique of multiple regression was used to develop the secondary model to verify and compare the performance results of the principal model. The primary intent of the developed model is to explore the measured influence of factors to predict the total cost of variations for a given proposed project with a realistic accuracy.

5.9 Model Validation

A simple validation procedure was adopted to test the performance of the model. The procedure focused on the satisfactory accuracy range of the model consistent with its intended application. The model was provided with new independent set of data and its output check against the actual results to calculate its accuracy range. The validation data was collected from twelve building projects. The full details of the procedure and the results of the validation with the professionals assessment are presented in chapter 9.

5.10 Summary

The main research objective is to analyse the construction process factors with particular reference to extent of variations on construction projects. The methodology adopted to accomplished this task involved an extensive literature review of texts and previous research studies together with professionals' and experts' opinions of the problem through informal interviews. This is followed by the development of the research model as a framework for the research.

Considering the quantitative nature of the research and the nature of the information required, the case study approach was considered to be the appropriate of data collection for the study. The method of analysis of the collected data, and model development and validation techniques were also outlined.

Chapter Six
The Extent and Sources of Variations on Construction Projects

6.1 Introduction

Previous research studies in construction have examined various aspects of conflicts, disputes and claims in an attempt to identify the sources or causes of the problem. Those studies have identified variations as one of the major sources of the problem faced by the industry. This is reflected in Hibberd's (1986) comment 'that the greatest problem in contract management is the issue of variations'. Clearly, reduction in the extent of variations would lead to an improvement in cost and time performance of construction projects. However, to achieve these objectives, first we need to have an idea as to the extent and sources or causes of variations, and second the factors influencing those sources have to be identified so that we can understand how they influence variations in order to find a way to control them.

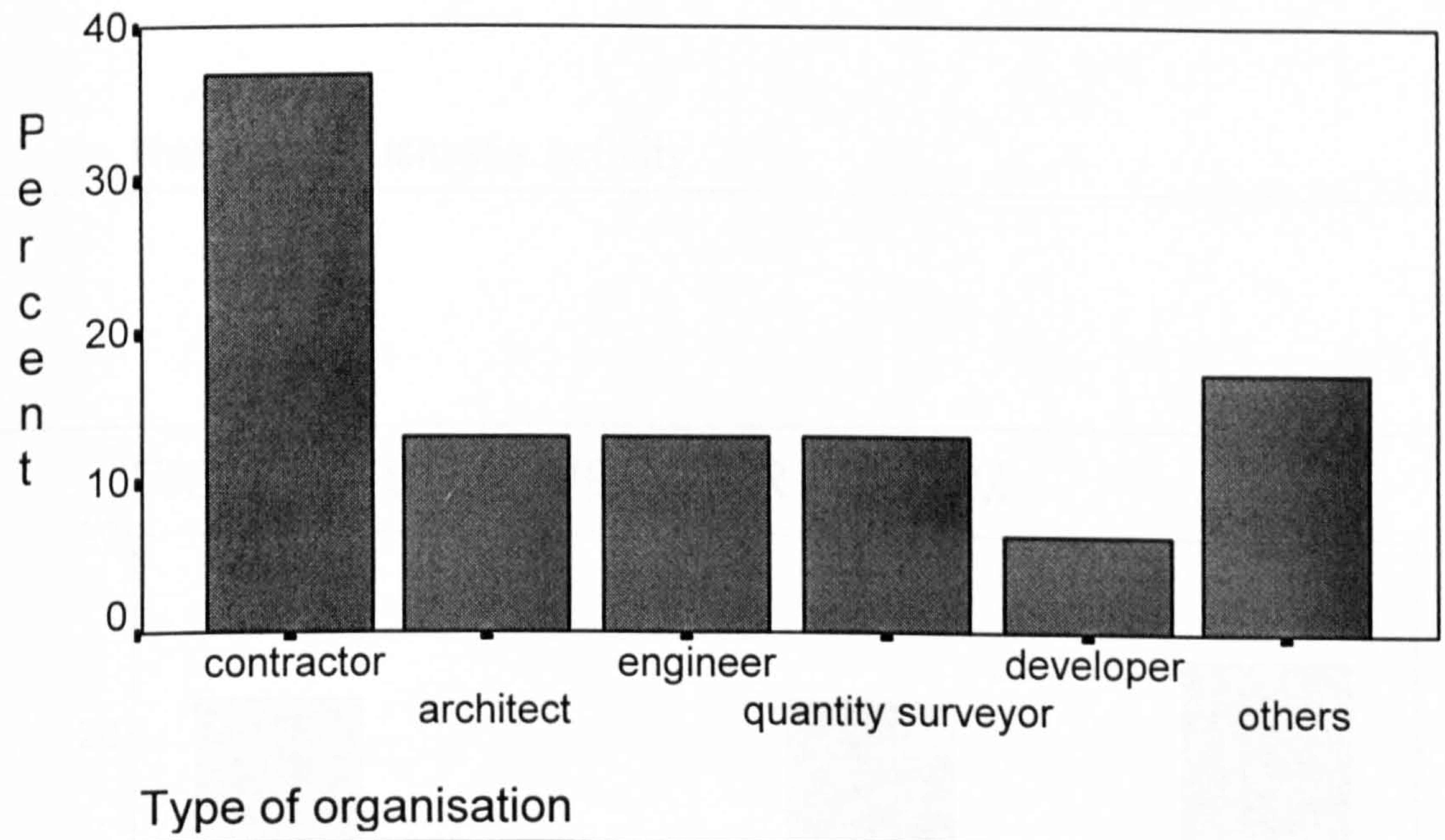
In chapter five, the research model and methodology adopted for the study was discussed. This chapter addresses the results of the first part of the research 'extent and sources of variations'. The second objective 'evaluation of factors influencing variations' is the subject of the next chapter. This chapter examines first, the extent of variations in relationship to their magnitude and frequency with references to project type, contract strategy, and tendering method. This is followed by a discussion of the results of investigation of the source or causes of variations. The rest of the chapter discusses the relative effectiveness of the variation clauses provision in the general conditions of contracts.

6.2 The Data Characteristics

The data for the study was collected from a wide range of organisations and companies involves with construction activity. Figure 6.1 shows the profile of these organisations.

The majority of these organisations are contractors making up 37% of the total respondents. The consulting organisations (i.e. Architects, engineers and quantity surveyors) in the sample have equal shares, 13% each, of the total number of organisations in the survey. The other organisations are client such as developers and the 'others' group made up of organisations including, private companies, government departments, local authorities and nationalised companies.

FIG.6.1 :PROFILE OF SURVEYED ORGANISATION



These organisations are involved in different construction activities. The nature of activities of the 45 organisations in the survey is shown in figure 6.2. From the figure, building and civil engineering contracting, and architectural design or project management was the dominant construction activities of these organisations in the sample, 26% and 22% respectively. The turnovers per annum of these organisations are shown in figure 6.3.

FIG.6.2: FIELD OF CONSTRUCTION

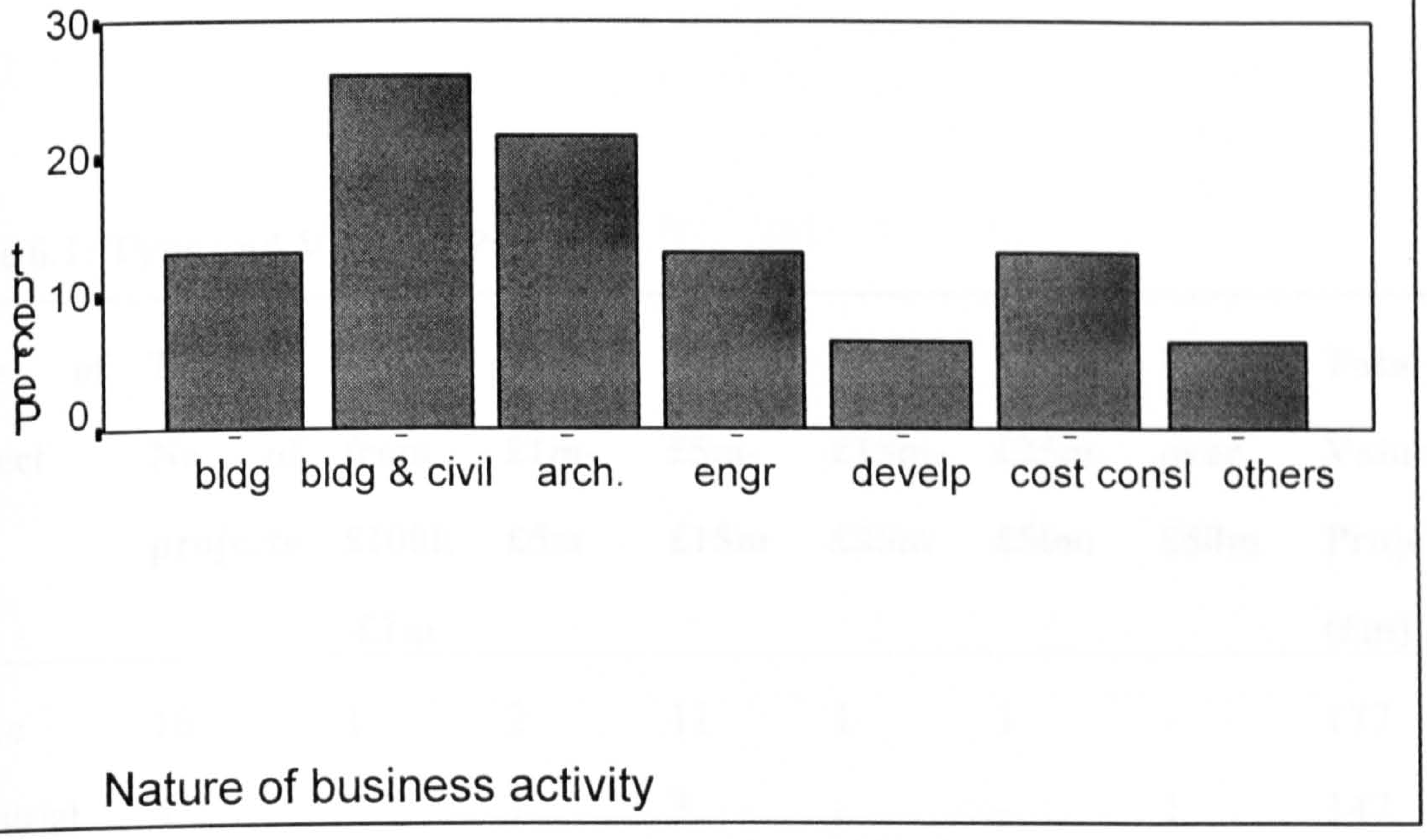
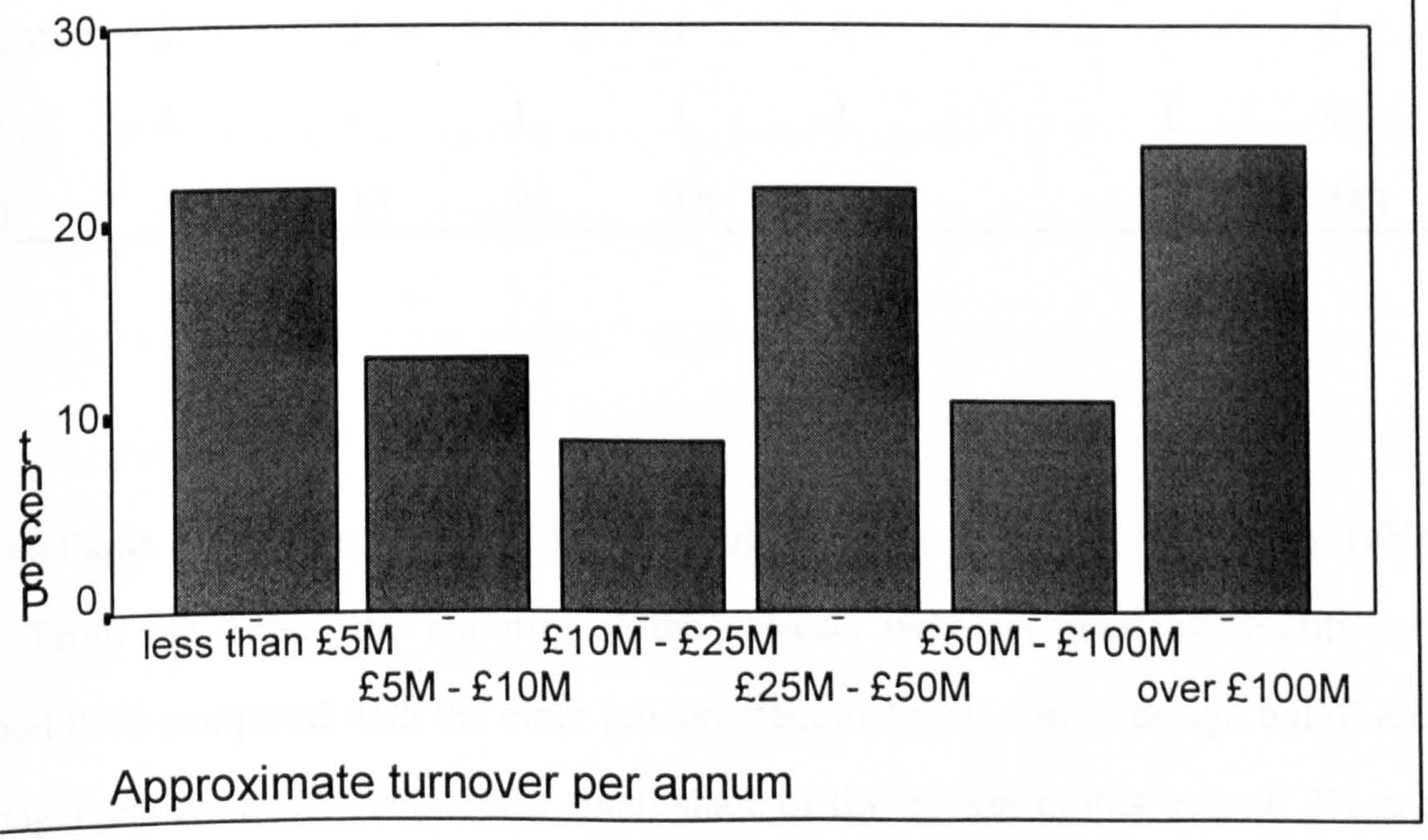


FIG.6.3: TURNOVER PER ANNUM



These organisations provided data from forty-five completed building projects. Table 6.1 shows the types and value of these projects. From Table 1, the majority of the projects were office buildings (36%) with total value of over £177M. Only 5 industrial building projects were in the study with a total value over £147M compared with the office buildings. The other types of projects included education and health buildings with values of approximately £17M and £38M respectively.

Table 6.1: Type and Value of Projects

Type of Project	Total No. of projects	Value from £100k -£1m	Value £1m-£5m	Value £5m-£15m	Value £15m-£25m	Value £25m-£50m	Value over £50m	Total Value of Projects (£m)
Office	16	1	2	11	1	1	-	177
Industrial	5	-	1	3	-	-	1	147
Health	3	1	-	1	1	-	-	38
Education	10	6	3	1	-	-	-	17
Residential	5	4	1	-	-	-	-	3
Leisure	2	1	-	1	-	-	-	7
Others	4	-	1	1	1	-	1	99
Total	45	13	8	18	3	1	2	488

The methods of procurement used for the projects in the survey are shown in Table 6.2. From the Table, the majority of the projects were procured by 'traditional' method 80% compared with the other procurement methods. Both 'design build' and 'management contract' method had small share of the market in this instant, 7% and

2% respectively. The table also shows the type of contract used. As can be seen from the table the majority of contracts used were 'lump sum' contracts 29(64%) and 'fixed cost' contracts 11 (24%) compared with other types of contract. The other types of contract were 'cost plus fee' and 'cost plus percentage fee' contracts- 1 each.

Table 6.2: Method of procurements and type of contracts

Procurement Method	Type of Contracts					
	Lump sum	**Cost plus fee**	**Cost plus % fee**	**Fixed cost**	**Others**	**Total**
Traditional	24	-	3	9	-	36
Management contract	-	1	-	1	-	2
Design build	5	-	-	1	1	7
Total	29	1	3	11	1	45

6.3 The Extent of Variations

The extent of variations on the forty-five projects surveyed are presented in this section. In quantifying variations, two measurements were considered; their magnitude, and frequency. The magnitude of variations defined the total cost variations (TCV) ordered per project. This is based on the summation of costs of variations contained on the variation order sheets. A variation sheet may contain a number of works to be done, each of which are taken as a separate variation, summed to derive the TCV of the particular project.

The frequency of variations defined the rate of variations ordered on the project per month (RVM). The RVM of a project is calculated by dividing the projects' TCV per the construction duration, i.e.

RVM = TCV/construction duration (in month)

These calculations were performed for each of the forty-five projects and expressed as a percentage of the project costs. The number and value of the projects studied by type in relation to the average percentage measurements of variations are summarised in Table 6.3. There are two significant features to note about the type and size of the projects. The first is that there is significant number of 'office' buildings accounting for 36% of the total sample with an average value of over £11m. In addition, this type of building in the study was clustered, eleven in all, in the £5 - £15m range. The majority of the 'industrial' buildings in the study, five in total, were also in this range. The second feature is that although there is this noticeable concentration of cases, none-the-less examples of a wide type of projects varying in sizes were in evidence in the study.

It is of interest to know whether various types of building, procured through various procurements and contract methods, are characterised by different performance in this regard. To investigate this presumption, the data was analysed by project type, contract strategy and method of tendering. The average TCV and RVM for each of the projects by types, contract strategy, and methods of tendering are shown in Tables 6.4-9.

Table 6.3: Sample Projects Profile by types and sizes

Proj. Cost Range	Office	Industrial	Health	Education	Residential	Leisure	Others
Less £1m	1	-	1	6	5	1	-
£1 - 5m	2	1	-	3	1	-	1
£5 - 15m	11	3	1	1	-	2	-
£15 - 25m	1	-	1	-	-	-	1
£25 - 50m	1	-	-	-	-	-	-
Over £50m	-	1	-	-	-	-	1
Total	16	5	3	10	6	3	3

6.3.1 By project type and size

The extents of variations by project type and size are given in Tables 6.4 and 6.5. Table 6.4 shows the percentage number of project by types and costs along with the average magnitude and frequency of variations. From the table, the industrial buildings generated the largest variations with an average of over 35% of the total cost of the project at an average rate of 0.8%. The health buildings were the reverse with magnitude of variations of only 4% at a frequency of 0.1% of the project total cost.

Comparison of the results of the projects by size with respect to the extent of variations is presented in Table 6.5. This table shows that the majority of the projects in the study were within the ranges '£5 - 15m' accounting for 39% of the total projects, with the least common projects being in the range '£25m - £50m'. As expected, the magnitude and frequency of variations on projects in this range were more than those generated in the other project ranges.

The results indicate the generally held presumption that project type and size would have a substantial bearing on performance in terms of magnitude and frequency of variations. As the use of the building varies, for example from a simple residential building to a more complex commercial building, so also would the value increase along with the uncertainty and risks involved all of which influence variations.

Table 6.4: Project types and variation measures.

Proj. Type	% No. Proj.	Av. Proj. Cost (million)	% Av. TCV	% Av. RVM
Office	34.8	11.07	9.0	0.8
Industrial	10.9	29.49	35.6	0.8
Health	6.5	12.57	4.4	0.3
Education	21.7	1.73	8.7	0.7
Residential	13.1	0.61	10.2	0.5
Leisure	6.5	5.29	6.6	0.4
Other	6.5	30.20	6.7	0.5

Table 6.5: Project size and variation measure.

Proj. Type	% No. Proj.	Av. Proj. Cost (million)	% Av. TCV	% Av. RVM
Less £1m	30.4	0.50	9.9	0.9
£1 - 5m	17.4	1.68	6.3	0.6
£5 - 15m	39.2	8.89	14.7	0.8
£15 - 25m	6.5	25.50	7.4	0.1
£25 - 50m	2.2	46.10	9.2	0.4
Over £50m	4.3	93.25	3.0	0.1

6.3.2 By contract strategy

The term 'contract strategy' is used here to describe the analysis of the cases by type of organisation structure used (i.e. method of procurement), and the contractual policies chosen for the execution of specific project (i.e. type of contract). The percentage number and average cost of the projects by method of procurement and type of contract with the percentage magnitude and frequency of variations are presented in Tables 6.6 and 6.7. Of the forty-five projects in the study, 80% were procured through the traditional method of procurement (Table 6.6). While the least used method is management contracting, 5%, with an average value of over £60m.

The result shows that the management method, thus the least procurement method in the study, generated far the largest variations with an average of over 10% of the total cost of the project at a frequency of 0.3%. In contrast, the traditional method generated the fewest variations followed by design build method. Performance, in terms of variations, the result suggests management contracting as the least efficient method.

Analysed results by type of contract is shown in Table 6.7, where the 'fixed cost' contracts (23.9%) and 'target cost' contracts (2.2%) with an average value of £5.18m and £8.6m respectively, produced the largest amount of variations. Thus, 'target cost' contract was the least dominant type of contract but generated the largest variations compared with other types of contract in the study.

This result, to some extent, rejects the generally held hypothesis that management contracting performed better than the tradition method (Sidwell, 1982; Nahapiet & Nahapiet, 1985; Naoum, 1987; Mohsini, 1984). The indication for the result may be attributed to the degree of integration and flexibility of the two methods. Traditional methods requires the design to be substantially completed and fully documented before the contract is put out for tender compared to management contracting which encourages the overlap of design and construction. The majority of the clients opting for traditional method are operating within the constraints of a tight budget that, as suggested by the result, limit the number of variations.

Table 6.6: **Procurement methods and variation measure.**

Procurement Method	% No. Pro.	Av. Proj. Cost (million)	% Av. TCV	% Av. RVM
Traditional	78.3	9.17	9.4	0.4
Management contract	6.5	60.70	10.5	0.3
Design build	15.2	5.39	9.5	1.1

Table 6.7: **Contract types and variation measures.**

Type of Contract	% No. Proj.	Av. Proj. Cost (million)	% Av. TCV	% Av. RVM
Lump sum	63.1	10.35	8.3	0.4
Cost plus fee	4.3	120.0	7.9	0.2
Cost plus % fee	6.5	1.16	7.1	0.6
Fixed cost	23.9	5.18	13.6	0.7
Target cost	2.2	8.60	20.9	1.7

6.3.3 By tendering procedure

The tendering procedure, as defined in this study, is the method used to select the contractor. Four methods of selection were identified from the study. The analysed results of the methods and the measures of variations are presented in Table 6.8. Selective tendering method shows up as the dominant method (78%) with average project values of £8.92m. The largest variations were generated on those projects with an average percentage of over 12% at a percentage frequency of 0.6%. In contrast, the direct nomination method generated the fewest variations. This variance in results supported the critic of the favoured method of selection, where the contractors is selected in competition decided by their bid for the project. According to Holt (1995) the contractor selection methods generally lack a universal approach and concentrate upon the tender sum as the major discriminating factor for selection. As indicated by the results, projects where the contractors were selected in competition, finished with largest amount of variations compared with the less favoured contractor selection method.

Table 6.8: Contractor selection methods and variation measure.

Selection Method	% No. Proj.	Av. Proj. Cost (million)	% Av. TCV	% Av. RVM
Open	8.7	19.59	9.8	0.2
Selective	78.3	8.92	12.7	0.6
Direct	6.5	9.78	2.5	0.1
Others	6.5	23.03	6.6	0.3

6.4 The Sources and Nature of variations

The results presented in the last section above revealed the prevalence of variations on construction projects. The results raised the questions as to what or who are responsible for the magnitude of the measured variations on the projects. As it was impractical to examine relevant documents necessary to elicit the required information due to confidential policy of the respondent organisations a novel approach was adopted. This approach was based on a subjective assessment of the respondents' perception of magnitude of variations originating from the ten identified sources. This approach provided an indication as to who or what is responsible for the measured magnitude of variations.

The questionnaire was designed to investigate the perceived frequency of variations originating from each of the identified sources, and the nature of the variations. The respondents were asked to rate on a 10-point scale the frequency of variations ordered on the projects attributed to each of the sources as follows:

Question: Please rate the following as a major source of the variations on the project.

- client choice
- client forced
- design change, etc.

Answer: On a 10-point scale, where, 0 = very low and 10 = very high.

The results were analysed in two-stages. In the first stage, the responses were sorted and analysed in groups; the clients, the consultants and the contractors. The analysis allowed the assessment of variability of the individual group to be compared.

In the final stage of the analysis, all the responses were analysed together and transformed into numeric scores to determine the perceptive rating of each of the identified sources of variations. The scores were transformed into relative important weightings (Olomolaiye, 1987; Kometa et al, 1995). The weightings for each source of variations were calculated from the following formula:

Relative important weighting (w_i) $= \Sigma W/A*N$

Where w_i = relative important index

W = rating of each source by the respondents on a scale 1-10

A = highest rate (in this case is 10)

N = total number of sample

The calculated relative important weighting ranges from 0 to 1, with 0 indicating least frequent, and 1 indicating the most frequent source of variations. Considering the weightings, the sources of variations were compared and ranked in order of their perceived frequency. This results is shown in Table 6.9. The table compares the group ranking of the sources with overall ranking along with the total scores and relative important index for each of the sources of variation.

Differences in the individual perception or judgement process is well documented in the literature on organisation behaviour and psychology (Tversky, 1967 & 1970;

Locke and Latham, 1990). To test whether there is any close agreement among the respondent groups, statistical rank agreement test was performed (Kendall, 1988). The tests using Kendall coefficient of concordance (*W*) test the null hypothesis that there is no agreement in ranking. This calculation is presented in Table 6.10. The table summarises the calculation procedure involved in determine W and the probability test of its value. The result suggested high agreement in ranks (with $p = 0.05$) between the parties. Thus, concluding that there is significant agreement in rank of the identified sources of variations.

6.4.1 The client as a source of variations

On the basis of Table 6.9, the clients stand out as the prolific source of variations. The client as primary source of variations generates variations by 'choice' or 'force'. Of the two secondary sources, 'client forced' variations ranked first overall with an index of 0.55. Those variations could be attributed to circumstances of which the client has no control over such as changes to the law/regulation or other external factors.

The 'client choice' source of variations ranked third overall with a relative index of 0.48. Those variations were attributed to the client exercising his choice and may not be the result of any control effect. For example, a client may order a variation to accommodate the end user requirements that might not be know before the design was completed.

Comparing the rating and ranking of the two categories of client source, to an extent, there is a close agreement between the consultants and the contractors. The consultants ranked the 'client forced' and 'choice sources' of variations' first and second, while the contractors rank both sources in reverse order (Table 6.9). The disagreements in ranking of the two sources by the clients, compared to the other two parties, as shown in the table are expected. However, the close agreement of both the consultants and the contractors with the overall ranking indicates lack of understanding of the majority of the clients as to implications of their decisions. This in turn could be attributed to their inexperience or lack of knowledge of construction process. The majority of the clients start building without establishing clearly enough what they want until it is too late.

6.4.2 The designer as a source of variations

Variations classified as originated from the designer (or design team) are mainly caused either, by choice, design defects or by inaccurate assessment of client brief. Of the three designer sources of variations, the 'designer choice' ranked 5^{th} overall with a relative index of 0.38 compared to other sources. The 'design defects' and the 'incorrect assessment of brief' ranked close, 6^{th} and 7^{th} with relative indices of 0.31 and 0.24 respectively.

Comparing the rating and ranking of these sources of variations by the three main parties, as shown in Table 6.9, both the clients and the contractors ranked 'designer choice' and 'design defects' equally, 3^{rd} and 6^{th} respectively. The disagreement in ranking between the designer and the other parties is not surprising, however, this is in line with previous investigations findings (Hibberd, 1980; Newcombe et al, 1986; Choy and Sidwell, 1991).

One of the fundamental obligations of the client and his adviser is to provide the precise requirements of the works to be undertaken. The level of completeness of the design indicates the degree of precision to be achieved. Precision based on incomplete design or detail would no doubt, as indicated in the result, lead to variations. The design process must be well managed so that it is completed on time and within the budget, and with all necessary decisions properly taken and fully and clearly expressed in the specification, and detailed drawings.

6.4.3 The management as a source of variations.

Classified under this group were sources or causes of variations such as; defect in documentation, inadequacy of information and the contractors. Inadequate information ranked 1st in the group and 4th overall with an index of 0.45. Ranked next are the contractor, 7th overall with an index of 0.24.

The results supported the findings of previous researchers (Higgin and Jessop, 1965; McDermott, 1994). According to BRE (1983) the majority of problems on construction projects were caused by inadequate information or poor documentation. The need for clarity of information and documentation during the construction process has earlier been suggested by Banwell, (1964) and Higgin and Jessop, (1965). Often documents are incomplete or unduly rushed and frequently result in changes to the agreed works.

Thus initiatives such as that of the Co-ordinating committee for Project Information (CCPI) and other organisations in the industry have over the years been directed at improving the quality of information and documentation at both design and construction stages. The applications or effectiveness of these initiatives that include a new code of convention and changes to the existing standard form of contract or the introduction of new standard form is difficult to measure or assess. However, the existence of the problem as indicated by the results is evidence.

6.4.4 The 'other' source of variations

This group consists of sources of variations that cannot be classified under any of the other three groups. The group include source/cause of variations such as; unforeseen events, statutory authorities, law or regulations. In the group unforeseen event rank 1st and 2nd overall with an index of 0.50. Typical example of variations attributed to this source are often cause by naturally influencing circumstances such as severe weather, unanticipated ground conditions, etc.

Table 6.9: The sources of variations

Group	Source	Group Ranking			Overall		
		Client	Consultant	Contractor	Total Scores	Relative index	Rank
Client							
	choice	5	2	1	218	0.48	3
	forced	4	1	2	249	0.55	1
Designer							
	choice	3	6	3	173	0.38	5
	defects	6	5	6	141	0.31	6
	brief	8	10	7	97	0.22	10
Management							
	document	7	9	8	103	0.23	9
	information	2	4	4	204	0.45	4
	contractor	8	7	10	106	0.24	7
Others							
	unforeseen	1	3	5	225	0.50	2
	miscellaneous	10	8	9	105	0.23	8

Table 6.10: Rank agreement test of sources of variations

Source	Rank						
	client	consultant	contractor	R_j	$\overline{R}_j$	$\overline{R}_j$ - R	$(\overline{R}_j - \overline{R})^2$
client choice	5	2	1	8	2.67	-2.83	8.01
client force	4	1	2	7	2.33	-3.17	10.05
designer choice	3	6	3	12	4	-1.5	2.25
defect	6	5	6	17	5.67	0.17	0.03
brief	8	7.5	10	25.5	8.5	3	9
document	9	10	7	26	8.67	3.17	10.05
information	2	4	4	10	3.33	-2.17	4.71
contractor	7	9	8	24	8	2.5	6.25
unforeseen	1	3	5	9	3	-2.5	6.25
miscellaneous	10	7.5	9	26.5	8.83	3.33	11.09
					Σ55		Σ67.69

$\overline{R} = 55/10 = 5.5$

$$W = \frac{\sum_{i=1}^{n}(\overline{R}_j - \overline{R})}{n(n^2-1)/12} = 67.69/82.5 = 0.821$$

$\chi^2 = k(n-1)W = 22.15$ where; k = group (eg. Clients, consultants, etc)

n = number of subject to rank

6.4.5 Nature of variations

The natures of variations are given in Table 6.11. From the table, the most frequent types of variations were straight-out additions to the work with relative frequency of 0.63. The second rated natures of variations are alteration to the original works, 0.55. Those are followed by substitution of the work with an index of 0.43. Other types of variations were omission and change of materials, with index of 0.30 and 0,25 respectively. The indication from the results suggests that the majority of those changes were ordered to reduce costs.

Table 6.11: Nature of Variations

Nature	Total Scores	Relative Important Index	Standard Deviation	Ranking
Addition	282	0.63	2.86	1
Alteration	242	0.55	3.04	2
Substitution	176	0.43	3.19	3
Omission	130	0.30	2.43	4
Change of material	99	0.25	2.64	5

6.5 An Evaluation of variation clause(s)

In the last sections, the extent of variations on the 45 projects in the study has been assessed along with the sources and nature of the variations measured on the projects. Variations, thus caused by circumstances, their magnitude and frequency, and their subsequent impact will no doubt be influenced by the contractual provision in the general condition of the contract. This presumption is generally held in the industry as reflected in the findings of previous research studies (Ibbs and Ashley, 1986; Bubshait and Almohawis, 1994). Both studies suggested that successful completion of construction projects in terms of cost, time, quality, and the satisfaction of the parties will depend on and be influenced by the general conditions of the contract. The contract conditions should anticipate the potential trouble area of the relationship between the parties.

Owing to this important role and intended applicability of the general conditions, many professional bodies, over the year, have developed standardised form of conditions of contracts. Those standard forms are widely used throughout the industry. However, the conditions of contract, whether standard or not, need to be evaluated by both parties to the contract as a potential source of project risk that needs to be assessed.

This section of the research is concerned with the exploration of how legitimate this assumption is, and what elements of the performance measures are important. From the collected data, three main types of standard condition of contracts were identified; JCT'80, IFC'84 and GC/Works. The distribution of these contract forms is presented in Table 6.12. The dominant forms are JCT'80 accounting for 84% compared to other forms IFC'84 and GC/Work (9% and 7% respectively).

Table 6.12: Distribution of the forms of contract

Group	JCT'80 (%)	IFC'84 (%)	GC/Works (%)	Total (%)
Clients	10 (26)	2 (50)	-	12 (27)
Consultants	19 (50)	1 (25)	2 (67)	22 (49)
Contractors	9 (24)	1 (25)	1 (33)	11 (24)
Total	38 (84)	4 (9)	3 (7)	45 (100)

Bubshait and Almohawis (1994) suggested 11 attributes to be used as a measure of performance of the general conditions of contracts. Nine of these attributes, relevant to variations, were used as performance measures of the variation clause. The nine attributes are presented and defined in Table 6.13. To measure these attributes, the questionnaire (last section) was designed to elicit the information on the performance of the variation clause in conditions of contract used for the projects based on the respondents' perceptions.

Table 6.13: Defined attributes of variation clause

Attributes	Definition
Definition	the clarity of which the clause define what constitute a variation.
Completeness	the degree to which the clause cover all contractual aspects of variation.
Fairness	the degree of fairness of the clause to all the contracting parties.
Consistency	the degree of conflict between the variation clause and other clauses in the general conditions of the contract.
Valuation	the degree of clarity of the clauses' stipulated procedure and rules for valuation of the varied works.
Practicality	the feasibility of implementation of the clause requirements.
Cost control	the degree of effect of the clause as mean of controlling the project cost.
Time control	the degree of effect of the clause as mean of controlling the project duration.
Performance	the degree to which the clause promote the attainment of the project performance.

The respondents were asked to rate each of the clause performances in relation to these nine attributes, on a 10-point likert scale. The data was then analysed in stages. In the first stage, the data was sorted and analysed according to the perception of; the clients, the consultants, and the contractors. The scores were computed and the average scores used to assessed the performances of the clause according to the respondent group.

In the final stage, the scores were transformed to relative indices to determine the relative importance of each of the performance attributes using relative index technique as explained in the last section. This technique, thus not an absolute measure, but it provides quantitative technique of assessment, based on the strength of the respondents' perception, of the importance of a particular attribute. The calculated indices were used to rank the attributes according to their importance.

Figures 6.4-12 give the pictures of perceived performance rating of the variation clauses. The figures, graphically, compare the average perception rating of the performances of the clause by the clients, the consultants and the contractors. From the figures, the three parties rated at least five performance attributes at 5 or over. The ranking of the attributes is presented in Table 6.14. The statistical test of agreement of the ranks is shown in Table 6.15. From the table, the hypothesis that the rankings are unrelated is rejected. Thus concluded that there is significant agreement ($p= 0.01$) among the ranking as indicated by the high coefficient of concordance (w) of 0.82.

Fig. 6.4: Comparison Rating of the Clause Definition of Variation

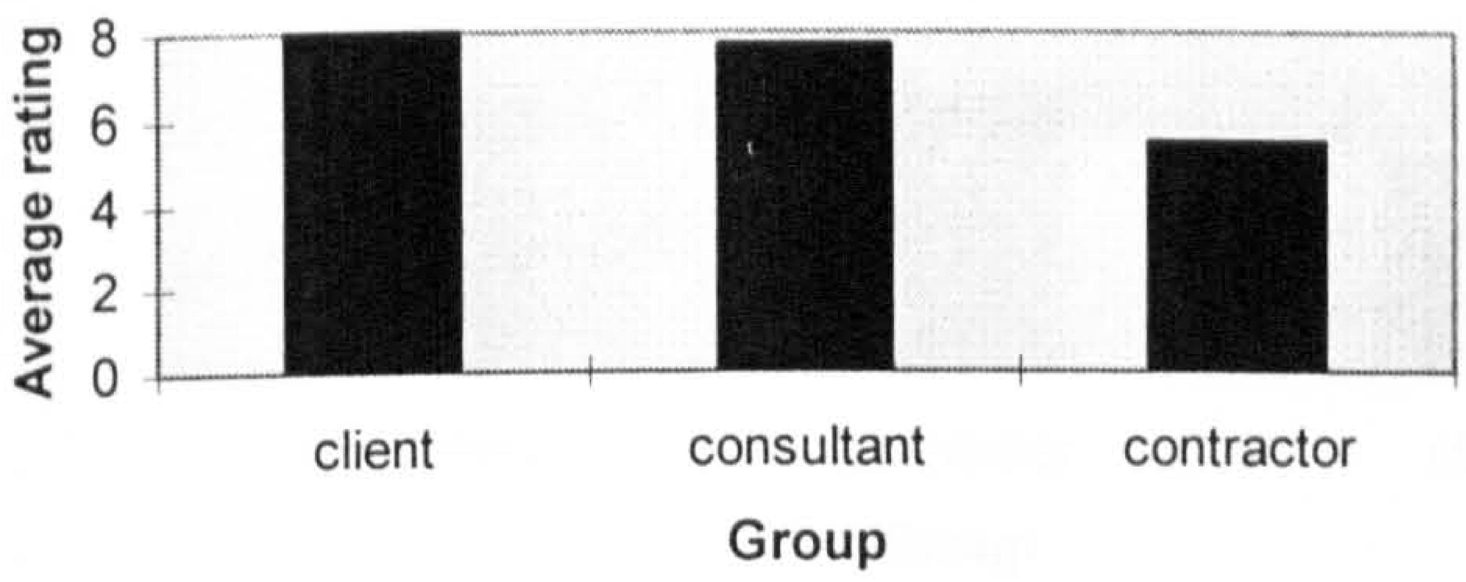


Fig. 6.5: Comparison Rating of the Completeness of the Clause

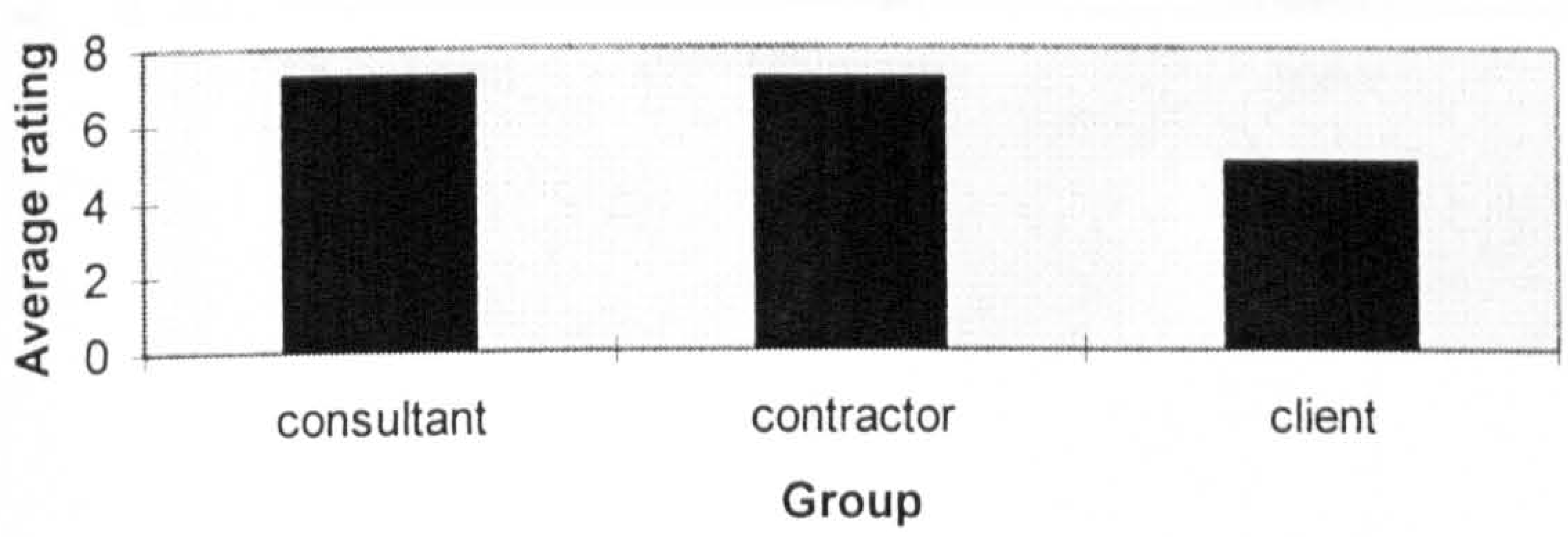


Fig. 6.6: Comparison Rating of the Fairness of the Clause

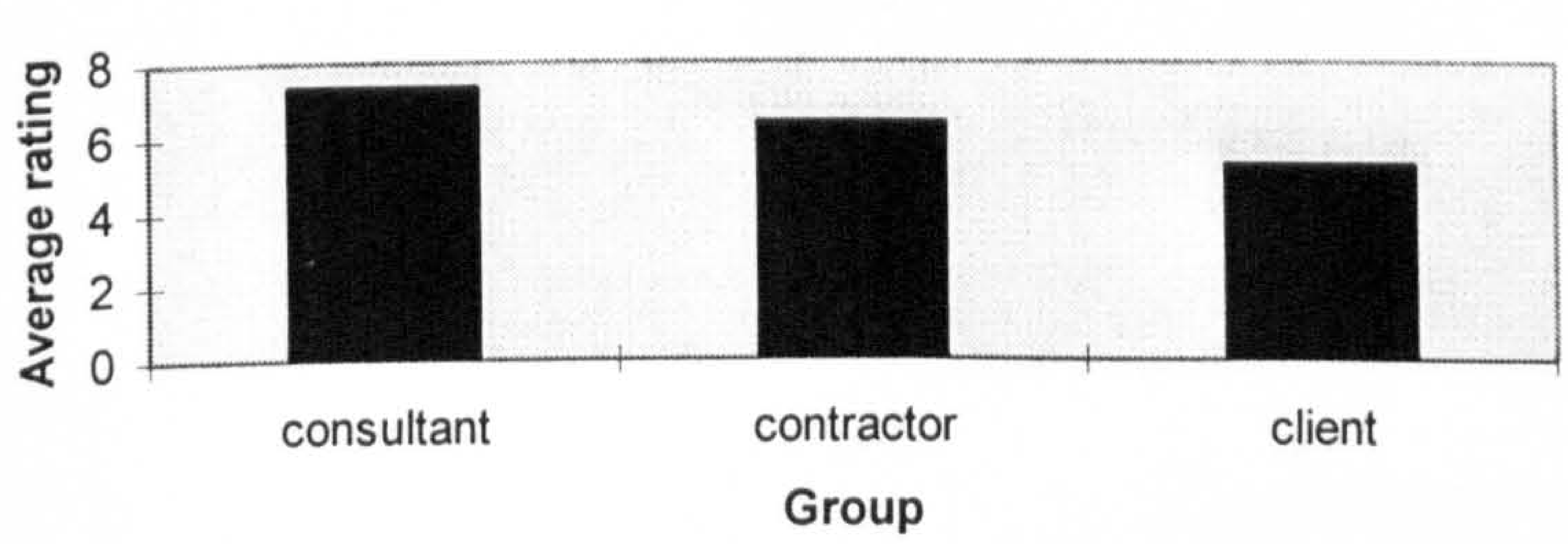


Fig. 6.7: Comparison Rating of Consistency of the Clause

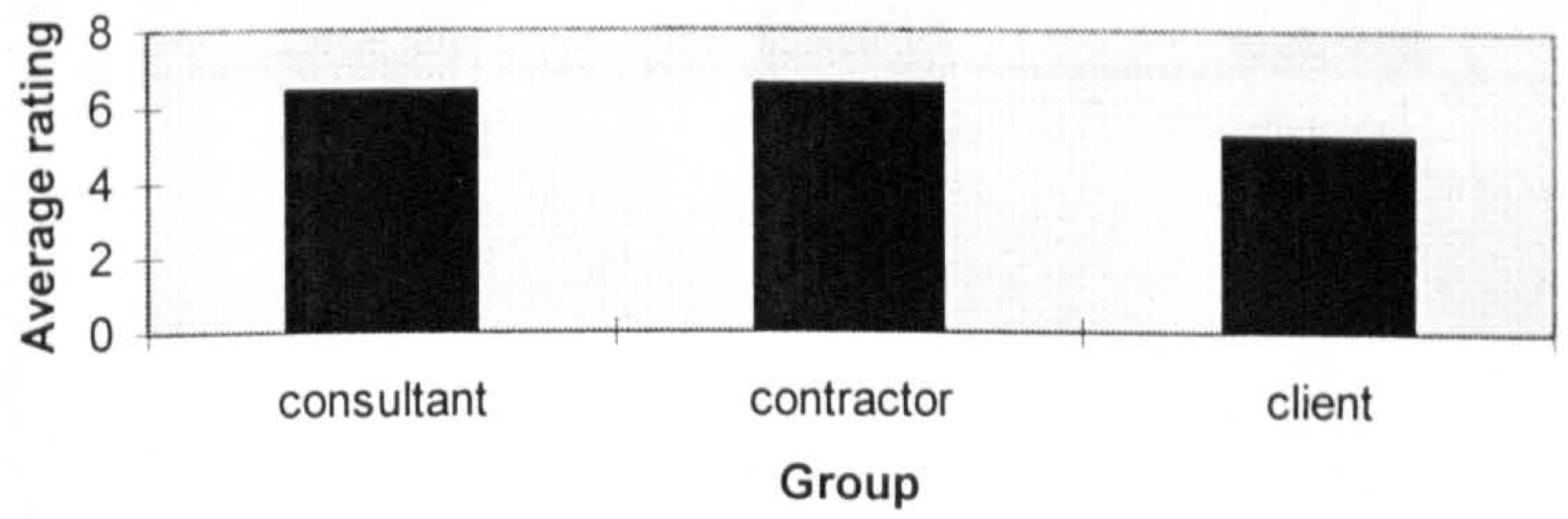


Fig. 6.8: Comparison Rating of Valuation Rule of the Clause

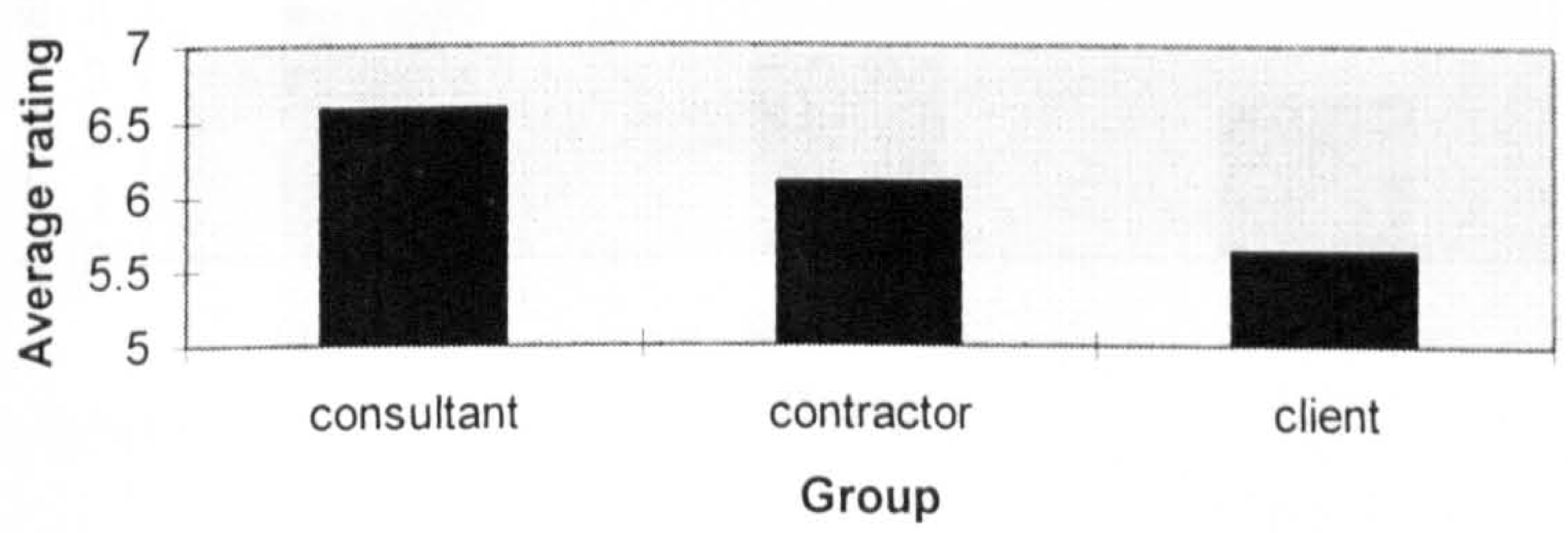


Fig. 6.9: Comparison Rating of the Clause in Terms of Cost Control

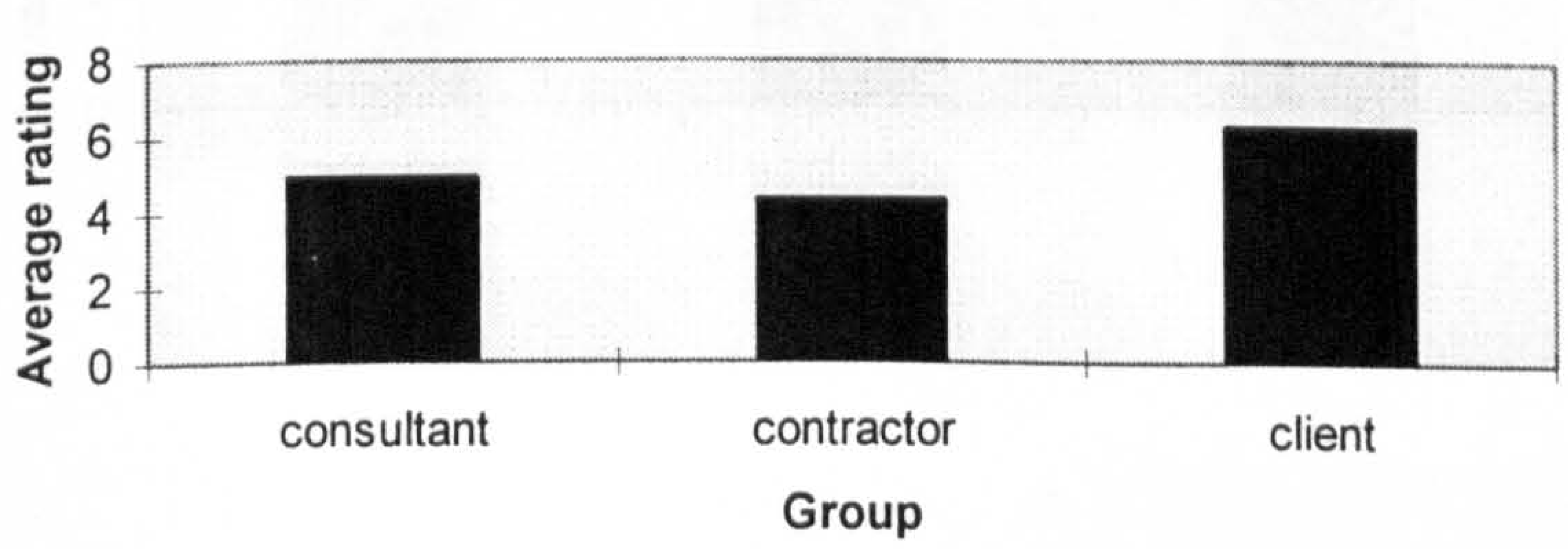


Fig. 6.11: Comparison of Practicality of the Clause

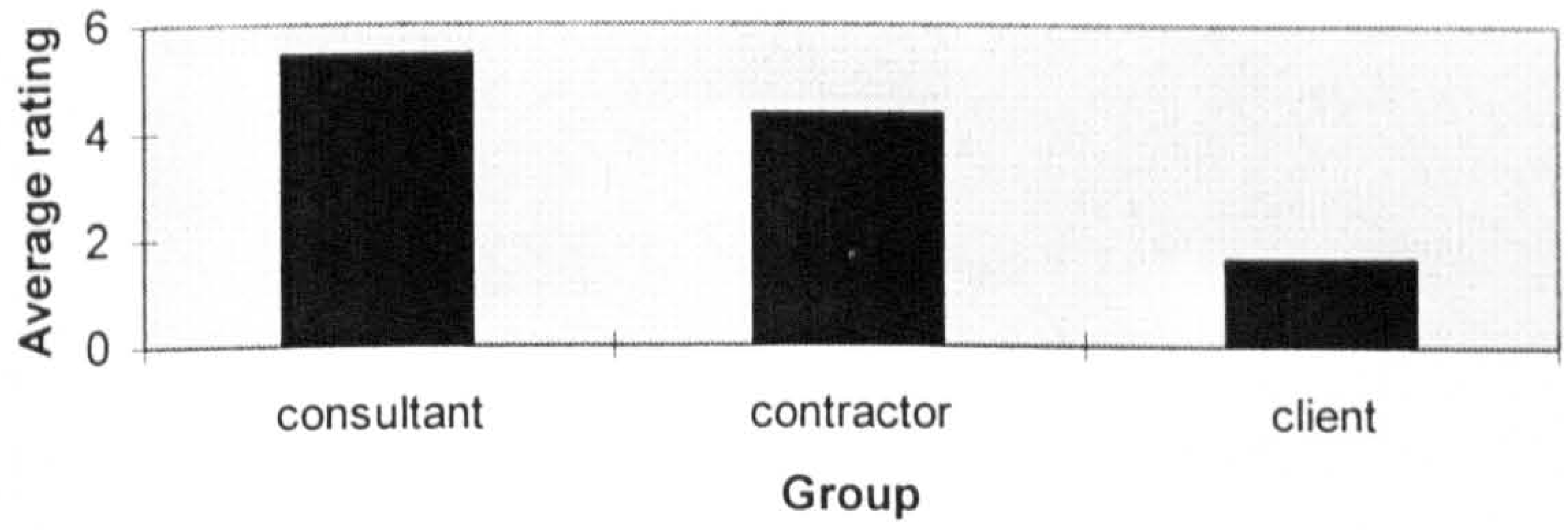


Fig. 6.12: Comparison Rating of the Clause in Term of project duration Control

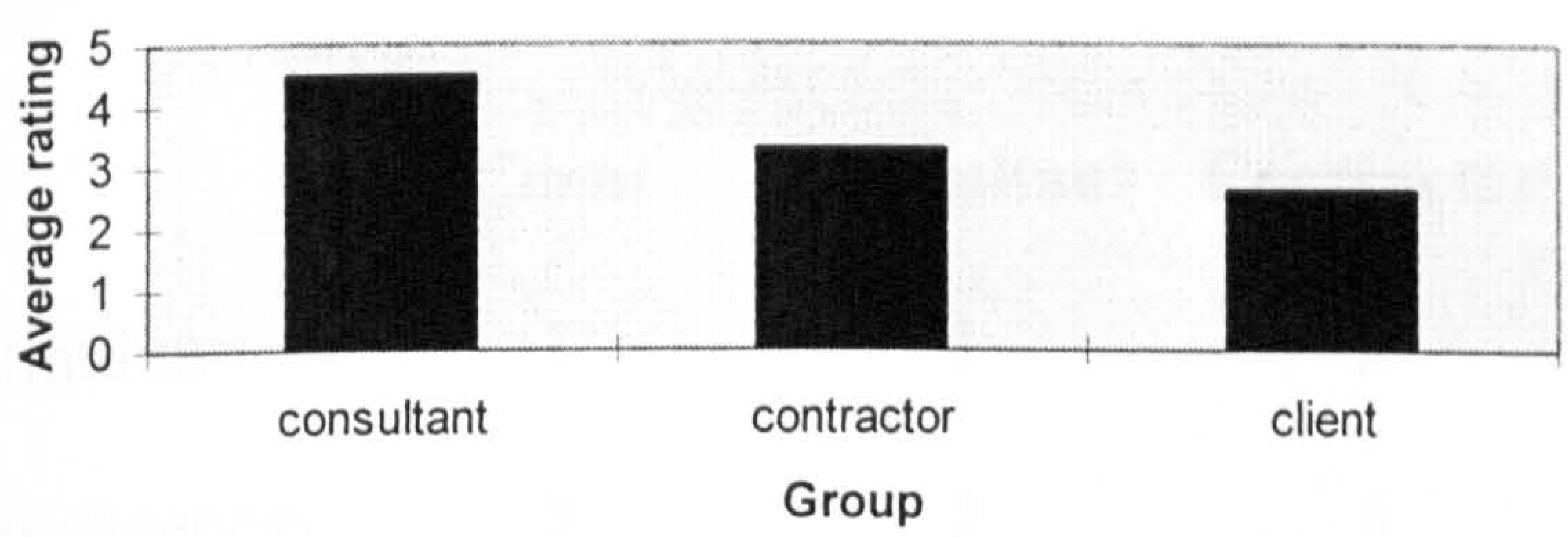


Fig. 6.12: Comparison Rating of the Clause in Term of Completion of the Project

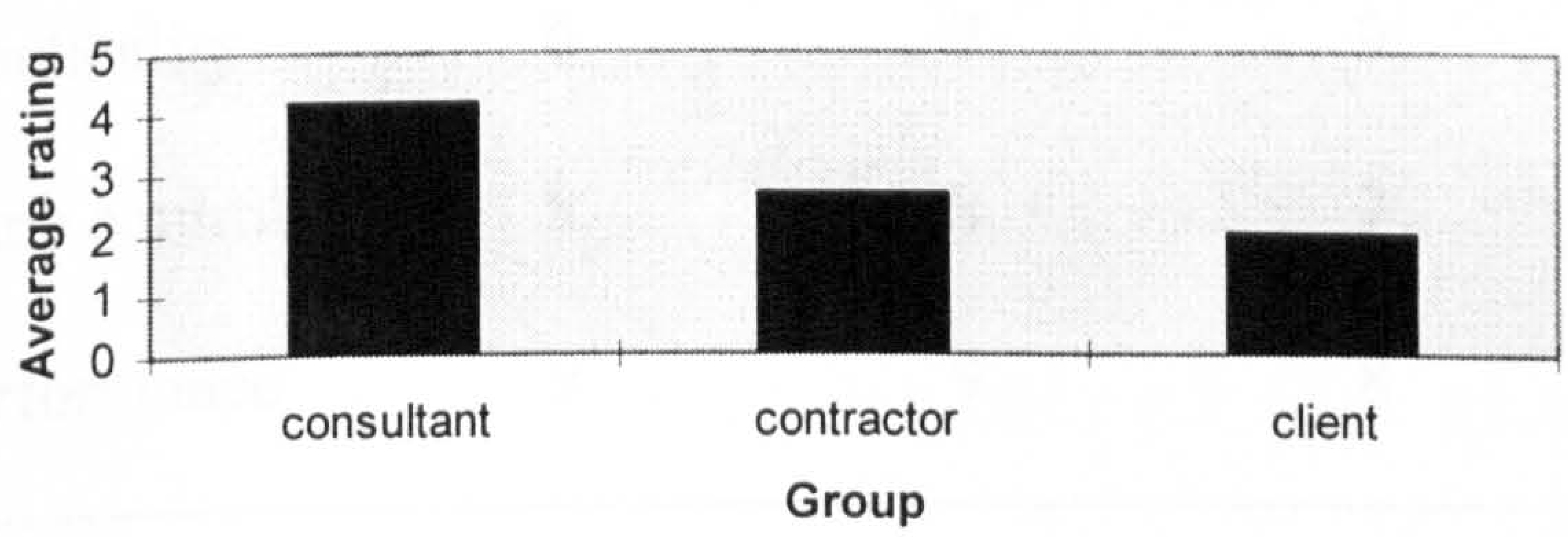


Table 6.14: Variation clause attributes

Attributes	Group Ranking			Overall		
	Client	Consultant	Contractor	Scores	Index	Rank
Definition	1	1	3	302	0.67	1
Completeness	3	2	6	278	0.62	2
Fairness	2	4	5	264	0.59	3
Consistency	5	3	4	257	0.57	4
Valuation	4	5	2	252	0.56	5
Cost control	7	6	1	200	0.44	6
Practicality	6	7	9	169	0.38	7
Time control	8	8	7	144	0.32	8
Performance	9	9	8	122	0.27	9

Table 6.15: Ranks test of variation clause attributes

Attributes	Rank						
	client	consultant	contractor	R_j	$\overline{R}_j$	$\overline{R}_j$ - R	$(\overline{R}_j - \overline{R})^2$
Definition	1	1	3	5	1.67	-3.33	11.09
Completeness	3	2	6	11	3.67	-1.33	1.77
Fairness	2	4	5	11	3.67	-1.33	1.77
Consistency	5	3	4	12	4	-1.00	1.00
Valuation	4	5	2	11	3.67	-1.33	1.77
Cost control	7	6	1	14	4.67	-0.33	0.11
Practicality	6	7	9	22	7.33	2.33	5.43
Time control	8	8	7	23	7.67	2.67	7.13
Performance	9	9	8	26	8.67	3.67	13.47
					Σ45.02		Σ43.54

$\overline{R} = 45.02/9 = 5$

$$W = \frac{\sum_{i=1}^{n}(\overline{R}_j - \overline{R})}{n(n^2-1)/12} = 43.54/60 = 0.726$$

$\chi^2 = k(n-1)W = 17.42$ where; k = group (eg. Clients, consultants, etc)

n = number of subject to rank (9)

On the basis of Table 6.13, the definitions of what constitutes a variation stands out as the most important attribute of a variation clause. In the past lack of clear definition of varied work has been identified as potential area of disputes regarding variations (Powell-Smith, 1988). A well-drafted clause that clearly defined what a varied work is would reduce dispute later when variations are ordered.

The second important attribute is the completeness of the clause as to the degree to which the clauses cover all aspects of variations. All aspects such as the procedure ordering, measurement, valuation and payment for varied works should be clearly stated.

Ranked third is the variation clause fairness to the contracting parties with a relative important index of 0.59. A client who orders a variation must be prepared to pay for the work. The disagreement of the ranking of the fairness of variation clause, especially in relation to payment, between the clients and the contractors suggests the issue to be potential subject of disputes. Variations are usually priced based on the conditions applying to the varied works at the time. Often enough, this is not the case because contractors are sometimes required to price the work on the basis of the unit price of the original bid that are based on prevailing conditions. Variations often impact on other works and duration of the project, in this case the contractor would be entitled to the additional cost to cover his loss.

The next important attribute is the consistency of variation clause. This attribute is ranked 4th with an index of 0.57. The level of conflict between variation clause and other clauses in the condition of the contract should be minimise if not eliminated entirely. Conflicting clauses cause disruptive impact on project which usually result in prolong disputes and expensive claims.

Of almost equal importance is the valuation of variations ranked 5th with a relative index of 0.56. Typical disputes regarding variations are often about valuation of the varied works. An efficient variation clause would be concise in its stipulation of how the varied work should be measured and valued, and clear in direction and rule that should be free of unnecessary information.

Finally, the use of variation to control both cost and time, practicality of implementation of the clause, and use as a tool to assess the project general performances, were all rated below 5. Thus perceived to be of less important some of these attributes are interrelated to the important attributes above. For example, practicality of the clause as defined by the feasibility of implementing the requirements of the clause is related to attributes such as the consistency and valuation attributes.

6.6 Discussion and Conclusion

All the projects investigated were fraught with variations with significant cost effects on the project costs. Variations of work during construction are inevitable and must be allowed for in the planning of the project. However, the prevalence of variations as revealed by the results raised the questions as to the source and nature of variations.

The categorisation of source of variations was similar to those used by previous researchers. The clients stand out as the most prolific source of variations compared with the other project team members. Often the clients initiate the changes due to circumstances beyond their control. The other major source/cause of variations are unforeseen events such as severe weather condition or ground conditions. The other major sources are the designers generating variations, mostly, to change or correct design defects. Of the nature of these variations, straight additions to the work during construction stand out as the most frequent type of variations on construction projects. Closely rated next to addition, were alteration and substitution of the work. The results thus confirmed previous research findings (Bromilow, 1970; Hibberd, 1980; Choy and Sidwell, 1991).

The relative complexity of the nature of construction project and the inevitability of variations requires the provision, in the general conditions of the contract, for ordering variations. While a number of research studies have focused on variation, none has addressed the issue of effectiveness of the variation clause. This study thus, evaluated the performance of the variation clause in order to determine the important attributes of the clause. These attributes are defined as constitution of a variation, completeness and fairness of the clause, consistency of the procedure for ordering variations and valuation rules. These attributes are often the disputed issues and frequently the subject of litigation involving variations (Powell-Smith, 1988). This information can be used to improve the amendment of variation clause and form the basis for assessment of their potential risk.

The next chapter discusses the research results of investigation of the potential factors influencing the extent and sources of variations discussed.

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CHAPTER SEVEN

AN EVALUTION OF FACTORS INFLUENCING VARIATIONS

7.1 Introduction

In the preceding chapter, the extent and causes of variations were examined and discussed with the performance of variation clauses provisions in the general conditions of standard forms of contracts. The need for those variations does not originate suddenly but is based on decisions influenced by many factors. This chapter, will discuss the results of the study investigation of those factors and their relative effects on the magnitude of variations.

For decades, many research studies have been conducted to investigate causes of performance deficiency in the industry (Bromilow, 1969; Morris, 1973; Sidwell, 1982; Rowlinson, 1986; Naoum, 1989), and all have identified variations as a major problem faced by the construction industry (Bromilow, 1970; Hibberd, 1980; CII, 1986; Gardiner, 1994; McDermott, 1994). In spite of those studies, the problem of variations as the major causes of conflicts, disputes and claims, still continue to plague the construction industry today.

However, those few studies on variations have been fragmented and have focused on isolated aspects of the problem. Clearly, the need to understand the factors influencing the decisions to vary the project after the contract has been awarded is important, particularly in planning for them and proper control of their impact on performance. This study is based on the premise that a truly meaningful research of variations requires a holistic approach in which all relevant factors are considered together rather than in isolation.

7.2 Factors Influencing Variations

Main hypothesis 1:- The magnitude of variations is a function of the clients' characteristics, project characteristics, design characteristics, procurement strategy, tendering procedure, production and environmental factors.

In chapter five, a theoretical model of factors influencing variations on construction projects was proposed and discussed. In order to suggest that one can utilise the factors as a basis for prediction of variations, it is necessary, first to establish whether the factors do indeed affect variations. Second, to test the first hypothesis of the study that the factors influence the magnitude of variations, and establish the relative importance of the factors in relation to their effects on variation.

To achieve these objectives, a two steps' approach was designed. The first step was designed to determine, empirically, the association between the factors and the variation measures. The association between the factors and variations were explored using correlation analysis technique (CAT). CAT allowed the significance and directionality of the relationship to be identified. Correlation coefficient of 0.20 and above (at 0.10 significant levels) were considered significant and discussed. From the results, the generals proposition that there is a relationship between variations and each factor can be tested.

The second step consists of measuring the extent of the effects of the significant related factors, identified from step one, on the magnitude of variations. To achieve this objective, the multiple regression analysis technique (MRAT) was employed. MRAT in principle, allowed the simultaneous effect of the factors upon the magnitude of variations to be assessed, and the relative importance of the factors on variations to be determined and compared. Since the factors were measured on difference scales, the standardised weights (beta) of the factors were used to calculate the relative important effects of the factors on the measured magnitude of variations.

Finally, the main hypothesis stated above is tested. For the purpose of testing, the hypothesis is break down to seven detailed sub-hypotheses. These are:-

Sub-hypothesis 1.1: The magnitude of variations is a function of the clients' characteristics.

Sub-hypothesis 1.2: The magnitude of variations is a function of the project characteristics.

Sub-hypothesis 1.3: The magnitude of variations is a function of the design characteristics.

Sub-hypothesis 1.4: The magnitude of variations is a function of the procurement strategy.

Sub-hypothesis 1.5: The magnitude of variations is a function of the tendering procedure.

Sub-hypothesis 1.6: The magnitude of variations is a function of the production factors.

Sub-hypothesis 1.7: The magnitude of variations is a function of the environmental factors.

To test the validity of these sub-hypotheses, they were expressed as null hypotheses for each factor group. The rejection or acceptance of the hypotheses are based on the statistical significance of the coefficient of multiple determination (R^2) of the regression analysis probability of significance of the F-ratio (ie. significant F).

7.2.1The client characteristics

Previous research investigations of the client have found that the client, as a subsystem of the construction process is more complex organisationally than previously thought (Cherns et al, 1983; Bresnen & Haslom, 1983). The client's role and decisions determine the project needs, team interactions, and the magnitude of conflicts and their resolution, as well as overall performance of the project. This role will be influenced by the clients' characteristics such as whether the client is public or private and, his experience/knowledge of construction process derived from the nature of his business. The research focuses on these characteristic factors, with the belief that they would influence the magnitude of variations generated.

Table 7.1 presents the clients' characteristics and the number of the projects studied. Of the forty-five project studied, twenty-two were publicly funded and the remaining twenty-three privately funded. Thirty-two of these clients were classed as experienced, and only thirteen classed as inexperienced clients.

Table 7.1: Project sample and client characteristics

Client characteristics	No. of projects	% of projects
Type: public	22	49
private	23	51
Experience: low	13	29
average	10	22
high	22	49

Null hypothesis 1.1 There is no relationship between the clients' characteristics and the total cost of variations.

Null hypothesis 1.2 There is no relationship between the clients' characteristics and the total number of variations.

The relationship between variation measures and client characteristic factors are given in Table 7.2. The table shows significant association between the client factors and the two variation measuring attributes. The positive correlation between the two measures of variation and the client type factor indicated that public client generates fewer variations compared to private clients. Similar results were observed between variation measures and the client experience factor. The more experience the client is, the fewer the magnitude of variations generated. Clients with construction related business (eg. local authorities) or clients whose main business incomes were derived from constructing building (eg. property developers) would possess adequate experiences of construction process.

Table 7.2: Correlation between variation measures and client characteristics

	Variation measures	
Client characteristics	**Total cost**	**Total number**
Type (CC1)	.500	.260
Experienced (CC2)	-.339	-.406

The relative influence and importance of the factors are given in Table 7.3. Examination of the results indicated that client 'type' is the most important clients' characteristic influencing the total cost of variations accounting for 20%. While the client 'experience' factor on the other hand shows to be the most important factor influencing the total number of variations, accounting for 11% of the total variance of the clients' characteristics influences.

Table 7.3: Client characteristics as determinants of variations magnitude

Client characteristic	Total cost of variations				Total number of variations			
Factors	**coeff. B.**	**B-wgt (Beta)**	**variance (%)**	**rank**	**coeff. B.**	**B-wgt (Beta)**	**variance (%)**	**rank**
CC1	2.166	.572	24	1	1.056	.343	11	2
CC2	-0.359	-.348	14	2	-.0343	-.409	14	1
Constant	9.072				3.397			
R^2	.379				.246			
F-ratio	8.331				4.453			
Signif F	.000				.009			

Overall, the results are in line with the findings of previous research studies of project performances (Bromilow, 1969; Sidwell, 1982; Naoum, 1989) and variations in particular (Bromilow, 1970; Hibberd, 1986) supporting the argument that public clients put more emphasis on certainty of cost to be provided at the outset of the project. This policy underlines the strait jacket effect of public accountability for public clients. The private client on the other hand emphasises the need for an accurate time estimate because any failure will affect commercial viability of a profit seeking organisation by altering their cash-flow forecast.

The other indication that fewer variations were generated by experience clients supported the suggestion (Naoum, 1989; Masterman, 1994) that experienced clients were in a better position to judge and properly evaluate their decisions, most of which would result in changes to the project, and the implications on the project cost and time. The inexperience clients on the other hand will have little knowledge of the implications of his decisions and what to expect.

The the null hypotheses 1.1 and 1.2 can be rejected on the basis of the significance of the F-ratio. Therefore the conclusion is that client characteristics do influence both the total cost and number of variations on construction projects.

7.2.2 Project characteristics

It has been considered useful to characterise construction projects in terms of their use, size, complexity and, duration. The reasoning behind this characteristic was that project vary and, to an extent differ in terms of the purpose for their construction which in turn determine the size and degree of complexity of their construction and incorporated technology as well as the duration of the construction process. Previous research has suggested that these characteristics would influence the magnitude of variations incidences on the projects (Bromilow, 1970).

Null hypothesis 1.3 There is no relationship between the project characteristics and the total cost of variations.

Null hypothesis 1.4 There is no relationship between the project characteristics and the total Number of variations.

Table 7.4 shows the relationship between the project characteristic factors and variation measures. As the table demonstrates, the project characteristics and variations' magnitude are significantly correlated. Most notable is the highly significant correlation between the variation measures and the project size and complexity. It indicates that the larger the size and complexity of the project, the larger the magnitude of variations on the project. The negative significant correlation between project type factor and the variations measures indicate directional increases in variations as the project uses' changes.

Table 7.4: Correlation between variation measures and project characteristics

	Variation measures	
Project characteristics	**Total cost**	**Total number**
Type (PC1)	-.369	-.179
Size (PC2)	.762	.676
Complexity (PC3)	.778	.557
Duration (PC4)	.312	.232

The relative importance of the project characteristic factors affecting the magnitude of variations is given in Table 7.5. As seen from the table, project complexity and duration are the most significant important factors influencing total cost of variations. The two factors accounted for 55% of the variance in variation cost. On the total number of variations, project size stands out as the most important project characteristic factor accounting for 39% of the variance in total number of variations.

Table 7.5: Project characteristics as determinants of variations magnitude

Project characteristic	Total cost of variations				Total number of variations			
Factors	coeff. B.	B-wgt (Beta)	variance (%)	rank	coeff. B.	B-wgt (Beta)	variance (%)	rank
PC1	-0.095	-.093	6	4	0.014	.017	1	3
PC2	0.246	.164	11	3	0.742	.608	39	1
PC3	1.484	.625	40	1	0.177	.092	6	2
PC4	0.019	.237	15	2	4.153E-04	.006	0	4
Constant	8.685				2.673			
R^2	.719				.461			
F-ratio	25.541				8.535			
Signif F	.000				.000			

In line with previous research findings, the result reaffirmes the suggestion that project characteristic are important factors influencing the magnitude of variations. Therefore, the null hypotheses 1.3 and 1.4 can be rejected. One possible explanation for the result is that projects become more complex as they become larger in size with increasing uncertainty hence their management becomes more difficult, thus increasing the need for variations to the project.

7.2.3 Design characteristics

Traditionally, the designer was the leader of the building team and adviser to the client. It has been suggested that his characteristics would influence his role and the project performances (Sidwell, 1982; Naoum, 1989) as well as the magnitude of variations caused by changes or correction of design during the construction stage of the project (Bromilow, 1970; Hibberd, 1986).

Null hypothesis 1.5 There is no relationship between the designer characteristics and the total cost of variations.

Null hypothesis 1.6 There is no relationship between the designer characteristics and the total number of variations.

Table 7.6 shows the relationship between variation measures and designer characteristic factors. From the table, the three designer characteristic factors, except for designer experience, are significantly correlated with variation measures. The effect and relative importance of the factors on the magnitude of variations are given in Table 7.7. As demonstrated in the table, 'design duration' followed by the 'percentage of design completed' are the significant important designer characteristic factors influencing both the total cost and number of variations on construction projects. The longer the design duration and the higher the percentage of design completed before the construction stage, the fewer the number and cost of variations. Therefore, the null hypotheses 1.5 and 1.6 above can be rejected.

Table 7.6: Correlation between variation measures and designer characteristics

Project characteristics	Variation measures: Total cost	Total number
Design duration (DC1)	-.462	-.363
Experience (DC2)	-.038	-.089
% of design completed (DC3)	-.237	-.265

Table 7.7: Designer characteristics as determinants of variations magnitude

Designer characteristic	Total cost of variations				Total number of variations			
Factors	coeff. B.	B-wgt (Beta)	variance (%)	rank	coeff. B.	B-wgt (Beta)	variance (%)	rank
DC1	-0.978	-.430	17	1	-0.587	-.318	10	1
DC3	-0.358	-.136	6	2	-0.406	-.190	7	2
Constant	9.705				2.886			
R^2	.231				.166			
F-ratio	6.318				4.167			
Signif F	.004				.022			

The indications from the results supported the suggestion that quality designs are produced when the designer is allowed the time to search for the best solution. Time is fundamental to the effective management of design process. If the design is not detailed or completed before the work is put out for tender, then all the necessary details cannot be made available to the contractors. Often, this inadequacy may not be obvious to the contractor at the time of preparing the tender. The implications during the construction stage are extensive design changes resulting in disruptions and delays which often enough leads to claims and disputes. It is often unpracticable to adopt this position in practice, especially if both the design and construction stages are overlapped, however proper management of design process and adequate allowance for the integration would no doubt reduce variations.

7.2.4 Procurement strategy

The procurement strategy involves selection of appropriate organisation structure and form of contracts to formalise the relationship and responsibility of the parties involved within the project. Previous research studies have demonstrated that the procurement strategy influences the performance of the project (Sidwell, 1982; Rowlinson, 1986; Naoum, 1989).

Null hypothesis 1.7 There is no relationship between the procurement strategy and the total cost of variations.

Null hypothesis 1.8 There is no relationship between the procurement strategy and the total number of variations.

The correlation analysis results are shown in Table 7.8. As given in the table, the only significant relationship exists between 'type of contract' factor and the total cost of variations. The result indicates that the variation cost increases according to the level of cost uncertainty of the contract type used. In terms of relative importance the factors accounted for 4% and 5% variances in the magnitude of variations (Table 7.9). On the basis of the results (sign. F= 0.2217 and 0.4678) we can accept both hypotheses 1.7 and 1.8, and conclude that there are no relationships between the total cost and number of variations and the procurement strategy.

Table 7.8: Correlation between variation measures and procurement strategy

	Variation measures	
Procurement strategy	**Total cost**	**Total number**
Procurement method (PS1)	.005	.183
Contract type (PS2)	-.208	-.127

Table 7.9: Procurement strategy as determinants of variations magnitude

Procurement strategy	Total cost of variations			Total number of variations		
Factors	coeff. B.	B-wgt (Beta)	variance (%)	coeff. B.	B-wgt (Beta)	variance (%)
PS2	0.041	.572	4	-0.131	-.177	5
Constant	12.783			5.664		
R^2	.044			.047		
F-ratio	0.956			1.044		
Signif F	.393			.361		

The result, thus not significant, indicates the importance of using appropriate form of a contract to handle uncertainty which often results in variations to the project. For example, in the traditional approach, the designs are adequately completed before the construction stage, in which case the use of a lump sum or a fixed cost contract may be considered appropriate compare to other method such as management contracts where design and construction are integrated. The level of integration affects the degree of uncertainty of the project and the magnitude of variations.

7.2.5 Tendering Procedure

The tendering procedure embraces the method adopted for the selection of the contractor and type of tender documentation used in inviting tenders. The contractors may be selected on the basis of a competition (either open or selective methods), or through direct nomination. In any of those cases, different document form the tender documents (eg. BOQ, specification, etc.). These factors are hypothesised as influencing the magnitude of variations on construction projects.

Null hypothesis 1.9: There is no relationship between the tendering procedures and the total cost of variations.

Null hypothesis 1.10: There is no relationship between the tendering procedures and the total number of variations.

Table 7.10 gives the results of correlation analysis between the variation measures and tendering procedure factors. The results support the null hypotheses that there is no relationships between the variation measures and tendering procedure factors. Thus not significant but the two factors accounted for 14% and 10% of the variances in both the total cost, and number of variations. The results are in line with Bromilow's (1970) findings for similar factors included in his detailed study of 25 projects in Australia. A possible explanation for the results may be that because of the majority of the projects in the study were let on selective bases (78%) with one form of bills of quantities or another compared to very few number of other methods and document types in the study, may have distorted the analysis and the results.

Table 7.10: Correlation between variation measures and tendering procedure

	Variation measures	
Tendering procedure	**Total cost**	**Total number**
Tendering method (TP1)	.076	.061
Document type (TP2)	.011	-.018

7.2.6 Production factors

The factors investigated under the heading of production factors were the construction duration, the contractors' experiences, the number of subcontractors, and the availability/adequacy of information.

Null hypothesis 1.11: There is no relationship between the production factors and the total cost of variation incidences on construction projects.

Null hypothesis 1.12: There is no relationship between the production factors and the total number of variation incidences on construction projects.

The correlation analysis results are shown in Table 7.11. As shown in the table only three of the production factors were significantly related to the magnitude of variations. Those factors are construction duration, availability/adequacy of information and, the number of subcontractors. The results indicate that the longer it takes to produce the building, and the less adequate the information available is, the higher the total cost of variations would be. Also, the more the number of subcontracts, the more the total numbers of variations.

Table 7.11: Correlation between variation measures and production factors

	Variation measures	
Production factors	**Total cost**	**Total number**
Construction duration (PF1)	.331	.224
Contractors' experience (PF2)	-.035	-.135
Number of subcontract (PF3)	.174	.261
Adequacy of information (PF4)	-.369	-.304

In terms of relative importance of the factors, availability/adequacy of information rank first followed by construction duration (Table 7.12). Both factors accounted for 19% of production factors variances on total cost of variations. On total number of variations, the only important factors were, availability/adequacy of information and number of subcontractors, accounting for 9% and 7% respectively. With significant F-ratios (0.01 and 0.05) the null hypotheses 1.9 and 1.10 can be rejected and we can conclude that production factors indeed influence both the total cost and number of variations.

Table 7.12: Production factors as determinants of variations' magnitude

Production Factors	Total cost of variations coeff. B.	B-wgt (Beta)	variance (%)	rank	Total number of variations coeff. B.	B-wgt (Beta)	variance (%)	rank
PF1	0.379	.301	10	2	0.183	.179	4	3
PF3	0.347	.149	5	3	0.476	.252	7	2
PF4	-0.793	-.373	11	1	-0.545	-.315	9	1
Constant	8.927				2.673			
R^2	.263				.202			
F-ratio	4.886				3.451			
Signif F	.005				.025			

7.2.7 Environmental factors

The term 'environment' entails all external influences on construction projects. According to Williams et al (1989) an organisation is embedded in economic, social, political and technical systems, and they influence the organisation strategy and structure, and technologies that are adopted. Construction projects as temporary organisations would also be influenced by these factors.

Null hypothesis 1.13: There is no relationship between the environmental factors and the total cost of variation incidences on construction projects.

Null hypothesis 1.14: There is no relationship between the environmental factors and the total number of variation incidences on construction projects.

The association between the variation measures and the environment factors is given in Table 7.13. The results indicate that only the 'political factor' correlated with the total cost of variations, while, total number of variations on the other hand correlate with the 'technological factor'. In terms of relative importance, none of the factors are significantly (Table 7.14). Therefore, we can accept the null hypotheses that environmental factors are not related to magnitude of variations.

Table 7.13: Correlation between variation measures and environment factors

Environment factors	Variation measures: Total cost	Total number
Economy (EF1)	-.116	-.004
Social (EF2)	.057	.037
Political (EF3)	-.252	-.105
Technology (EF4)	.077	.249

Table 7.14: Environment factors as determinants of variations magnitude

Environment Factors	Total cost of variations: coeff. B.	B-wgt (Beta)	variance (%)	rank	Total number of variations: coeff. B.	B-wgt (Beta)	variance (%)	rank
EF3	-0.759	-.319	6	1	-0.428	-.222	4	2
EF4	0.433	.190	4	2	0.606	.328	7	1
Constant	12.720				4.505			
R^2	.095				.105			
F-ratio	2.205				2.470			
Signif F	.123				.096			

7.3 Revised research model

Several factors were identified, through the review of previous studies, as influencing the magnitude of variations on construction projects. Those factors were conceptualised in the research model in chapter five. It is clear from the results that the magnitude of variations on construction projects are indeed influenced by a number of factors. Of the seven categories of factors identified, four were established as significantly related and influenced both the total cost and number of variations. These factors, are, the clients' characteristic, project characteristics, designer's characteristics, and production factors. The reversed research model, based on the results, is shown in Figure 7.1 annotated with degree of their relative effects (R^2) on the magnitude of variations, and significant interrelationships of the factors.

As shown in the figure, the project characteristics stand out as the most important influencing factor group influencing the magnitude of variations. Previous studies (Sidwell, 1982; Rowlinston, 1986) have highlighted the importance of project size and complexity to project success. In line with the findings of these studies, the study results' indications confirmed the effects of these factors on variations. As suggested (Sidwell, 1982; Senior, 1990) the complexity of the construction projects, derives from either the proposed uses or required technology to be incorporated in the building or method of technology/method of construction to employed, often results in longer project duration and increasing risk of uncertainty all of which would increase the magnitude of variations. For example, a large project with relatively high complexity and uncertainty, especially if the design and construction stages are integrated, would take a long time to build and would generate more variations compared to a simple project with minium complexity and construction duration.

Clients' characteristics rank next as another important factor group influencing the magnitude of variations. Type of client and their experience of construction process are important factors that would influence the client's decisions to make changes to the project. Public client for instant, would put more emphasis on the certainty of cost from the project outset because of limited funding available and the increasing public accountability of his spending. Compared to a private client such as a developer for example, the emphasis on time certainty would be higher as the earlier the project is completed, the more the commercial viability of the project would be, and the more the magnitude of variations generated in an effort to complete the project in time. So also would the influence of the client's experience of construction process, as an experienced client would have adequate knowledge of the repercussion of his decisions on the project.

Other important factors, are the production factors. The study showed that the more the inadequacy of information and duration, the more the risk of uncertainties on the project with consequential effects on variations. This indication supported the findings of the Building Research Establishment (1981). According to the BRE, the majority of serious problems during the production of a building are caused by inadequate project information. Ideally, construction would not start on the site unless adequate information is available, unfortunately, the environment of construction projects are any thing but ideal. However, the need to improve the quality of information passing between design and construction and allowing adequate time for the processing of the information as suggested by Banwell (1964) more than thirty years ago is still applicable today if the efficiency and economy of construction process are to improve.

The designer characteristics are another influencing factor on variations. The results showed that the more percentage of design completed giving the designer enough time, the fewer the magnitude of variations. As suggested previously (Laufer and Cohenca, 1990) a low percentage of design completed prior to the start of construction results in considerable disruptions and delays to the project as a result of changes and correction to the originally agreed works. Even on a project procured through management contracts, where design and construction stages were overlapped, the reduction in overall project time that would result from the overlapping may be significantly shorter than planned and financial saving expected may in fact turns into a loss. Thus, often impracticable, giving the designer adequate time to search for the best design solution, and fully detailing and completing the design would reduce the magnitude of changes and correction during the construction with significant impact on performance.

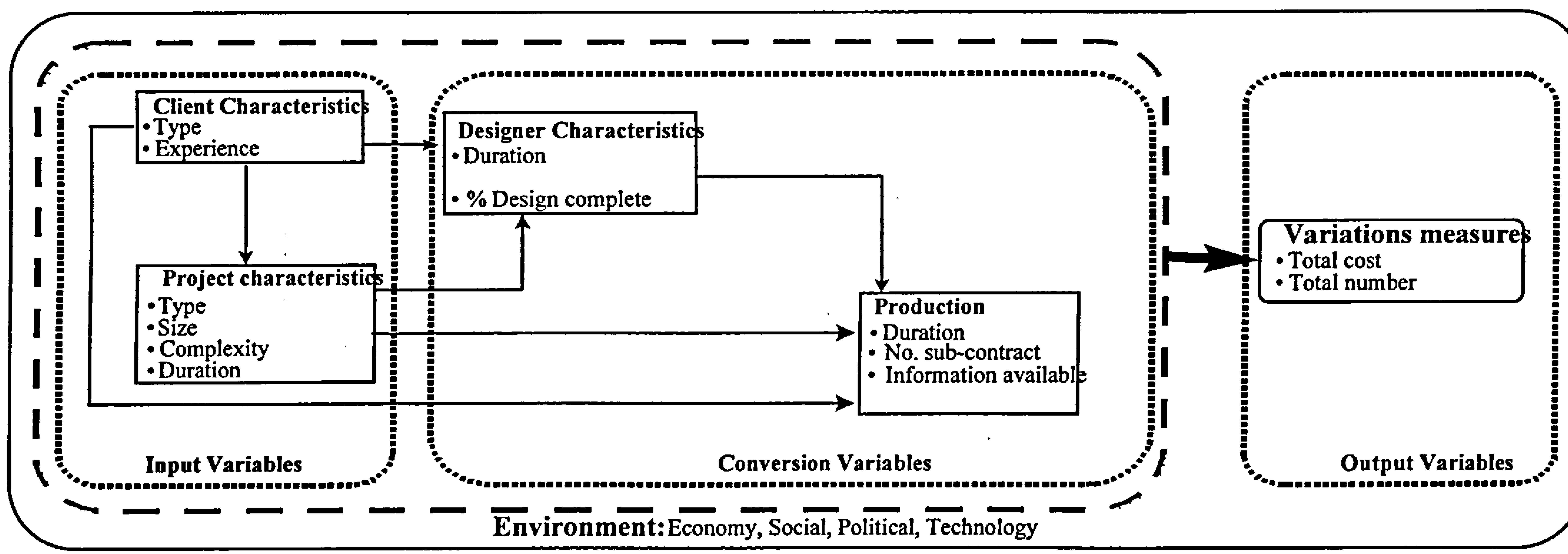


Fig. 7.1: Revised Research Model

7.4 Variations and project performance

The results discussion so far has focused on factors influencing the magnitude of variations. However, can any direct links be ascertained between the variation measures and project performance? To answer this question, two objective indicators were used to measure performance. These indicators were, the cost, and time overruns. Cost/time overrun are defined as the percentage differences in cost/time, plus or minus, between the final contract cost/time and the original cost/time.

For each of the forty-five projects study, the cost and time overruns were calculated. The summarised results are presented in Table 7.15. The table overall, showed that substantial number of the projects finished over the cost and time of the projects. The majority of the projects finished within 10% over the budget, while majority of the time overruns (44%) were more than 10% of the planned duration of the projects.

Table 7.15: Projects performances

	Performance measures			
	Time outcome		**Cost outcome**	
	no	%	no.	%
Under/within 5%	17	38	13	29
Up to 10% overrun	8	18	20	44
Over 10% overrun	20	44	12	27
Total	45	100	45	100

The relationship between performance and variation measures are given in Table 7.16. As shown in the table, there are significant relationships between performance and variations. The direct correlation between total cost of variations and cost/time overrun, and the total number of variations and cost overrun, indicates that an increase in the number and cost of variations ordered would increase the extent of disruption and delay to the project resulting in both time and cost overrun. Thus not significant, the relationship between number of variations and time overrun can only be explained, as indicated by the negative correlation, that the number of variations does not necessarily increase the project time since majority would not have any significant impact on the project duration.

Table 7.16: Correlation between variations and performance

Variations measure	Performance measure	
	Time overrun	Cost overrun
Total cost	.263	.840
Total number	-.220	.630

In line with previous research findings (Bromilow, 1970; Jahren and Ashe, 1990; Semple et al, 1994) this result indicates that variations are strongly related to the cost and time performance. According to Bromilow, a project's cost is generally controlled by variations, in order to keep the cost within the budget regardless of the effects these changes may have on the project. The indications of the result support the argument but, because it is impossble to gain access to detail documents of these projects to fully test the validity of the argument therefore the results can only be considered as an indication.

7.5 Summary

Past research studies on problems of variations were concentrated on their nature and source/cause (Bromilow, 1970; Hibberd, 1980; Choy and Sidwell , 1991; Moselhi, et al, 1990), communication and social relationship impact (McDermott, 1994), and variations impact (Ashley and Mathews, 1986). These studies have failed to appreciate that decisions taken to make changes to the project after the contract have been signed are influenced by several factors, and those factors act in combination rather than in isolation on the decisions.

In this chapter, these significant factors influencing the magnitude of variations on construction projects have been discussed and the significance of their influences demonstrated, and the interrelationship of the factors, generally, which may induce indirect influence on variations were underlined. The results generally support the main hypothesis of the study that the magnitude of variations will be dependent on the client and project characteristics, designer characteristics and the production factors. Also, the presumption that the variations can be associated with project performance is tested and confirmed that increase in magnitude of variation would results in increase project time and cost.

In view of the results discussed in this chapter, it is clear that, variations are inevitable on construction projects, however any effective plan for them and control of their impact requires the understanding of those factors which influence the decision to order variations. There is no doubt that if the magnitude of the influence of these factors are understand and considered in the plan for the occurrence of variations, a realistic and efficient plan can be make for them in order to reduce and contain their impact on the project performance.

CHAPTER EIGHT

ARTIFICIAL NEURAL NETWORK MODEL OF VARIATIONS

8.1 Introduction

In chapter three a number of construction process factors were identified through the literature review as factors influencing the magnitude of variations on construction projects. The conceptual model of the perceived relationship investigated was conceived in chapter five. The preceding chapter reported the investigation results and discussed the relationship and relative influence of construction process factors on the magnitude of variations on construction projects. Those identified factors are of central importance to any realistic model of variations' contingency. Therefore, the relationship and influence of these factors is the basis of the model developed and tested in this chapter.

8.2 Issue of Variations' Contingency Allowance

The construction industry has been consistently criticised for poor performance in attaining its clients requirements. Time and cost overruns were predominately common and were well documented (NEDO, 1975; RICS, 1979). The incidence and magnitude of variations was identified as a major cause and a focus of much of the criticism (Bromilow, 1969, 1970; Hibberd, 1980, 1986; Latham, 1994).

Variations during the construction period are time consuming and costly. Thus accepted as an inevitable part of construction, variations are a major cause of disruption, delay and disputes and generate significant cost impact. Contingency allowance allocation is one of the most important aspect of variations control framework, as reviewed in chapter four, and probably the most neglected aspect of the project planning process. There is no empirical method or tool, quantitative or otherwise, available for forecasting justifiable realist variations' contingency.

The conventional approach is to include a percentage of the project cost as contingency in the pre-contract budget for their occurrences. The allocated contingency based on this method is largely judgmental and arbitrarily allocated. However, construction projects are unique; as they may have distinctive set of objectives, require the application of new technology or technical approaches to achieve the required result, or even duplicate a given set of results in an entirely different environment (Hamburger, 1992). This uniqueness makes the conventional method based wholly on the project manager/supervisors' experience and intuition in danger of overly simplistic and unrealistic (Yeo, 1990).

The objectives of the contingency allocation are to ensure that the budget set aside for the project is realistic and sufficient enough to contain the risk of unforeseen cost increases. Therefore any realistic contingency must serve as a basis for decision making concerning financial viability of the variations, and a baseline for their control. After all to manage variations means being able to anticipate their occurrences and to control or monitor their associated cost (Ashley et al, 1986). The remaining sections of this chapter describes the development a model to predict the total cost of variations (i.e. variations' contingency) on a proposed construction project. The methodology adopted for the development and testing of the model are described.

8.3 Artificial Neural Network Model of Total Cost of Variations

The development of an artificial neural network (ANN) model is highly problem-dependent, and there is no established approach or formal methodology. In the absence of any structured approach, three phases methodology was used to developed the model of total cost of variations. The three distinct phases are; the design, implementation, and model simplification phases. Each of these phases are described.

8.3.1 Model design

The model design phase consist of two main tasks; problem analysis, and selection of the model system attributes. The analysis of the research problem starts with the review of previous studies of construction project performance problems with particular attention to variations.

The research aim (chapter one) was based on two main assumptions, as hypotheses in chapter five that; (1) the magnitude of variations on construction projects are influenced by a number of factors present in the construction process, and (2) by identifying and using the relationship between variation and the factors, the total cost of variations can be more realistically predicted as a contingency to facilitate the control and containment of variations during the construction of the project. A total of twenty-two characteristics factors, grouped under six main headings, were investigated as predominantly influencing the magnitude of variations on construction projects. Accordingly, these factors are used in the present model to form the pattern associated with the magnitude of variation occurrences on the projects.

Selecting the attributes of the model involves analysis and evaluation of these indicative factors and understanding their correlation and the significance of their influences on the magnitude of variations. The classification and measurement of these factors is given in Table 8.1 below (see appendix E for detailed definition), and the evaluation of the correlation and significant importance of the factors has already been discussed in the previous chapter. It is only after the problem has been properly analysed and the modelling attributes identified that the implementation of an ANN based model is possible.

Table 8.1: Classification and measurement of factors

Factors Category	**Factors**	**Coding Scheme**
1. Client characteristics	type (CC1)	1= public 2= private
	experience (CC2)	1= high 2= average 3= low
	nature of business (CC3)	1= public services 2= developer 3= private/manufacturing

Factors Category	Factors	Coding Scheme
		co.
2. Project characteristics	type (PC1)	1= office
		2= industrial
		3= health
		4= education
		5= residential
		6= others
	size (PC2)	£000s
	complexity	cost/month
	duration	in month
3. Organisation strategy	designer's experience (DC1)	1= high
		2= average
		3= low
	design duration (DC2)	in month
	% of design completed before tender (DC3)	1= fully
		2= average
		3=low
	procurement method (PM1)	1= traditional
		2= management contract
		3= design & build/management
	type of contract (PM2)	1= lump sum
		2= cost +fee
		3= cost + % fee
		4= fixed cost
		5= others
	method of tendering (TP1)	1= open
		2= selective
		3= direct
		4= others
	type of tender document (TP2)	1= BOQ
		2= approximate BOQ
		3= schedule of rate
		4= others
	contractor experience (PF1)	1= high
		2= average
		3= low
	construction duration (PF2)	in month
	adequacy of information (PF3)	1= high
		2= average
		3= low

Factors Category	Factors	Coding Scheme
	number of subcontracts (PF4)	1= high 2= average 3= low
4. Environment Factors	economy (EF1)	1= low 2= average 3= high
	social (EF2)	1= low 2= average 3= high
	political (EF3)	1= low 2= average 3= high
	technology (EF4)	1= low 2= average 3= high

8.3.2 Implementation

The implementation phase of the model development constitutes four main aspects; the selection of the network paradigm, data processing and, training and testing of the network model. The ease of these implementation phases, depends on software resources. There are basically two ways of implementing an ANN model. The first is to 'handwire' the network algorithms into a software using programming languages like C or C++. This is however time consuming and requires a good knowledge of computer programming. The other way, as used in the research, is to used a neural network simulation package. The research ANN model was implemented using the 'NeuroSolution'neural network simulation package (from NeuroDimension Inc) on PC. The model implementation does not require knowledge of computer programming because the program contained several predefined neural paradigms. Each of the implementation aspects of the ANN model development are described next.

Selecting network paradigms

The first step in implementation of an artificial neural network model is to select appropriate network paradigms by matching the problem with the available paradigms' capabilities. The neural network paradigms varies with regards to the type of inputs patterns they accept, the output pattern produced and the learning characteristics (chapter 4).

There are no algorithms or rules for determining the best neural network paradigm for a particular problem. However, the potential problem area in construction management which can benefit from application of ANN techniques has been identified with suggestions for suitable network structure (Moselhi and Hegazy, 1991). Considering the nature of our problem a simple three layers feedforward with backpropagation neural network structure is chosen to model the total cost of variations on construction projects. The neural network paradigm is currently the most popular and especially suited to the nature of this research.

The first layer, an input layer, consist of twenty-two processing elements(PE), determined by the number of factors which has been identified to influence the magnitude of variations on construction projects (Table 8.1). This layer operates as a simple input buffer and uses a sigmoid transfer function to distribute each of the input values to each of the processing elements of the second layer.

The second layer is the hidden layer. The determination of the number PEs in the hidden layers is more of an art than science assisted with experiementation and heuristics in making the choice based on trial-and-error approach. The idea is to start with one hidden layer and add more if necessary however, a single layer was found to be adequate to solve our problem. The initial number of PEs in the layer to start with is determined by a rule of thumb based on trial-n-error. Since there is only a single layer, we start with the equal number of input PEs, twenty-two. This approach is based on the concept that too many PEs incurs a long training time or allows the network to memorise the data rather than extracting the general pattern that will allow it to handle data not used in training it. Applying this rule and the initial number of PEs were reduced experimentally. The optimum number of PEs found to be adequate is five. Each of the processing elements uses a non-linear sigmoidal transfer function which has the same number of weights as the number of input attributes.

The final layer, the output layer, consist of a single processing element which would be interpreted as a regression node giving the estimated total cost of variations. The output signals from each of the hidden layer's transfer functions feed into the output element and are further processed by the output layer function to predict what the total cost of variations would be.

Data processing

The data used to developed the model was collected through a structured questionnaire from 45 building projects completed between 1989 and 1994 in the UK. The projects covered a wide spectrum of building types, from simple residential buildings to very complex office and industrial buildings. The data consisted of both categorical and numerical measurements.

Research data are often imperfect and need to be properly prepared to be suitable for modelling. Thus, artificial neural networks can extract essential information from raw data, however, without preparation of the data, the network model would be too complex and take very long computation time. It is therefore essential to properly prepare the data in order to reduce both the model complexity and computation time.

The data preparation mainly involves transformation of the data into a format suitable for ANN modelling. The transformation converts the raw data into either discrete or continuous formats to be meaningful to an artificial neural network. Discrete value transformation is done by assigning 'zeros' and 'ones' for the applicable factors. Client type for example, which can either be 'public' or 'private' becomes zero or one. In continuous value transformation, the raw data is transformed into real numbers, each assigned for a given factor (e.g. project cost). The number could then be transform by scaling or normalisation. These methods are described in detail in a number of literature providing guidelines for data preparation for analysis and modelling (Bailey and Thompson, 1990; Lawrence, 1991; Crook, 1992). Adopting any of these techniques depends on the type of data and neural paradigm selected.

For the research problem, the data contain both discrete values, and continuous values suitably scaled. The scaling transformed the continuous values into a range between zero and one, while the discrete values are transformed into binary. The transformed data is then utilised to train the network model.

Training The Neural Network

The supervised training method is used to trained the network. Supervised training is the most commonly used method and is based on the network learning to predict outcomes for known examples. The network then compares its predictions to the desired answer and 'learns' from its mistakes. This training method uses 'back-propagation' algorithms. The network training starts with randomly assigned weights in the network connections between the layers. Each set of input and output pairs is then presented to the network one at time. After each presentation, the network compares its output to the actual values and the errors (i.e. the difference) is propagated backwards and used to adjust the weights. This training process continue until the errors are within the acceptable limit.

Standard methodology used for training the network involves splitting the data set into two portions and then using one portion to train the network, and the other portion to assess its performance. Of the forty-five projects, thirty-five were randomly selected to eliminate any bias for training, and the remaining ten cases were set aside for testing the model later to assess its predictive performance.

8.3.3 The network model simplification

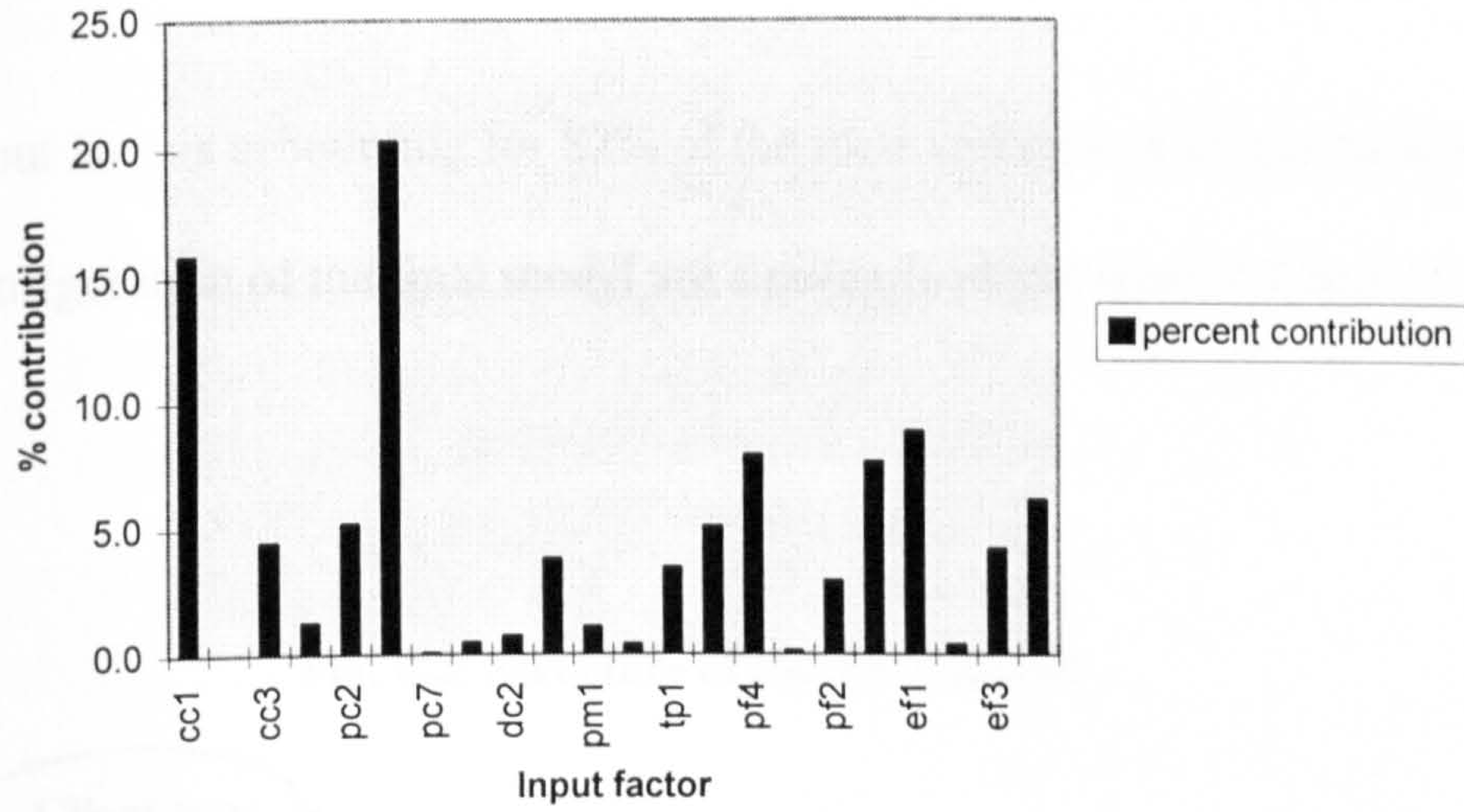
The final phase of the ANN model development is the simplification of the resulting network model. The law of parsimony dictates that when alternative explanation of a phenomenon are available, the simplest explanation would be preferred. Building a simple model would save time in data collection for the validation of the resulting ANN model.

The model simplification is primarily a process of examining, by 'pruning', the developed network model to determine which input factors are not necessary (contributing) to the model solution (Sietsina and Dow, 1991). By pruning the network, the model dimensionality is reduce by removing those less contributing input factors with no effect on the model predictive capability.

Several researchers has, over the past three or five years, proposed a number of innovative approaches for the purpose of simplifying network models through causal analysis of the input factors and the output prediction of an ANN models (Garson, 1991; Glorfeld, 1996). Garson (1991), for instance, proposed a technique based on the network weight to determined the relative importance of ANNs input attributes by partitioning the output layer connection weights into components associated with the input attributes. This technique, however, involve a complex mathematical calculation to make the technique time consuming and complex to use.

The NeuroSolution program, however, provides a sensitivity analysis facility which can be used to determine the contributing effects of each of the input factors to the output of the model. The basic idea of the sensitivity analysis is to shift, slightly, each input factors and note the corresponding changes in the output. Given the existence of this facility within the neural network simulation program, the contribution of each of the twenty-two input factors were determined by varying each factor a number of times while the other factors remain constant, and the effect of the factor on the output computed. Figure 8.1 presents, graphically, the percentage contributions of each of the input factors to the prediction of the total cost of variations. The percentage contributions of the factors is used to rank the each of the factors according to their relative importance.

Fig. 8.1: Input factors percentage contributions



Having determined the relative important of all the input factors, a 'backward' elimination approach is then used to remove the less important inputs one by one starting with the factor with the smallest contribution. Each time an input factor is dropped, the model is re-trained (by 16,000 iterations) and tested, and the mean standard error of both the training and test data sets noted. This procedure is repeated for the other input factors in turn and continued until only one input factor remains. In all, a total of twenty-two models were developed and tested. The problem is now reduced to selecting the best model

To select the best model a simple heuristic method is employed based on the mean standard error (MSE) of the models predictions. Given the mean standard error (MSE), the model with minimum MSE is selected as the best model. The model consists of ten input factors accounting for 82% of the total variance of all the factors. The structure and configuration of the final model are summarised in Figure 8.2 and Table 8.2 respectively.

Fig. 8.2: Structure of the ANN model

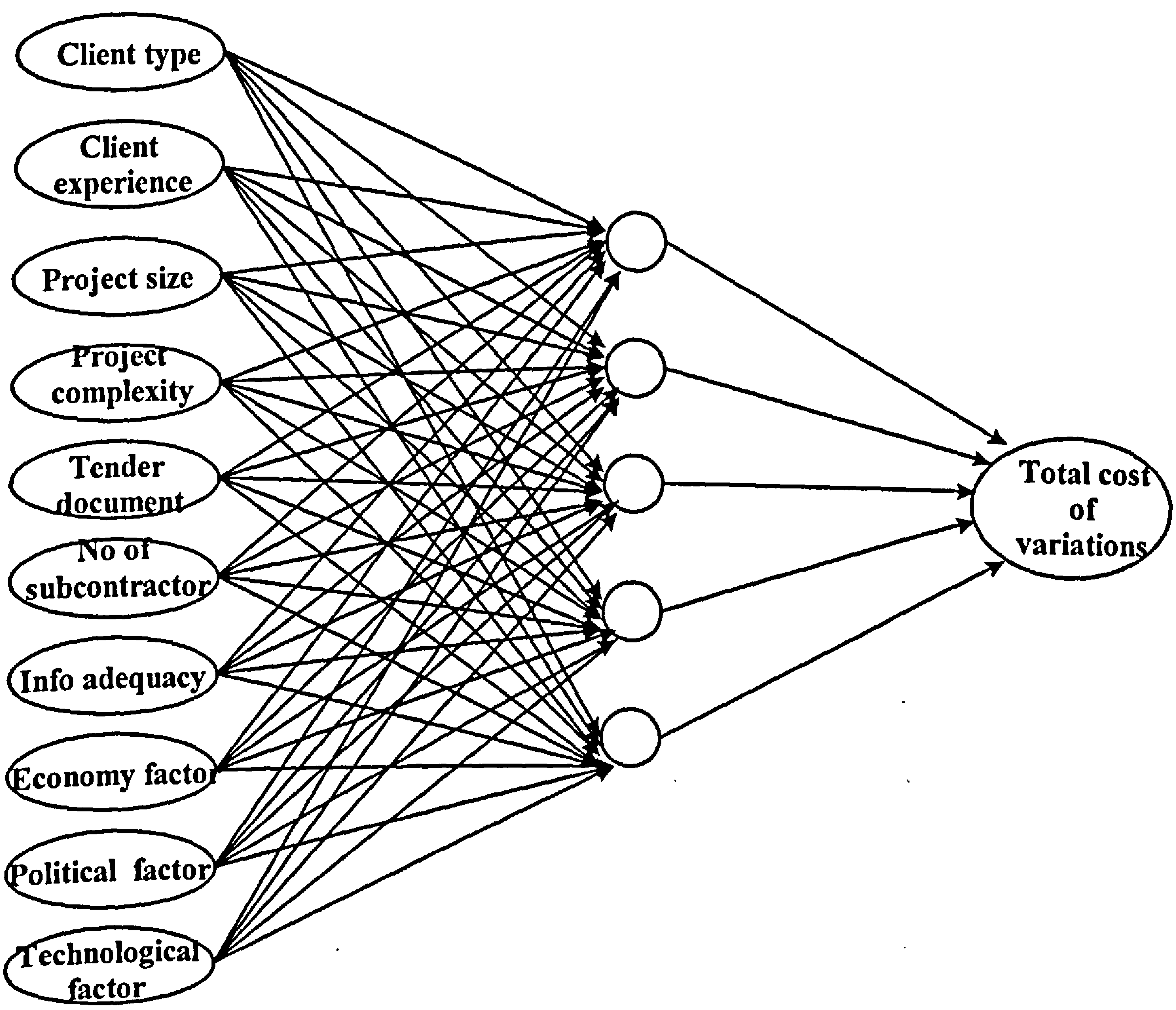


Table 8.2: ANN model configuration

Parameter	Value
Type of input	Discrete and continuous real numbers
Transfer function	Sigmoid
Network connectivity	Fully connected
Learning algorithm	Momentum
Learning rate coefficients (η)	0.10 and 0.05
Momentum coefficient (α)	
Number of hidden layer	One hidden layer
Number of PEs in input layer	Ten PEs
Number of PEs in hidden layer	Five (determined by trial-and-error)
Number of PEs in output layer	One

8.4 ANN Model Performance

The model predictive performance is assessed by examining the residual, the difference between the actual and the model's predicted total cost of variations. This assessment was carried out by, visual, and quantitative examinations. The visual examination requires plotting both the actual and the predicted values for all the cases, and examining the differences. The quantitative examination used two relative measures of prediction performance based on the model prediction error. The two measures are the 'mean percentage error' and the mean absolute percentage error'. The measures were calculated, based on the model predicted values using the following formulas:

1. Mean percentage error (MPE)

$$MPE = \frac{\sum_{i=1}^{n} PE_i}{n}$$

$$PE_i = \left(\frac{x_i - p_i}{x_i}\right)100$$

where PE_i is the percentage error of project i; x_i is actual total cost of variations for project i; p_i is the predicted value for project i; and n the total number of project.

2. Mean absolute percentage error (MAPE)

$$MAPE = \frac{\sum_{i=1}^{n} (AE_i)}{n}$$

$$AE_i = \sqrt{(x_i - p_i)^2}$$ Where AE_i = absolute error of project i.

The results of the performance assessment are summarised in Tables 8.3. The Table shows the model predictions of the total cost of variations for thirty-five projects compared with the actual values. As seen in the table, the model predictions error ranges between 0% and 2.5% with an absolute percentage error (MAPE) of only 0.26%. The small MAPE derived from the model predictions indicates that the network has achieved internal validity, that is, it has been trained and ready for testing.

Table 8.3: ANN model performance results

Project	Total Value of Variations	ANN Predictions	Error	PE	APE
1	25000	25019	-19.32	-0.08	0.08
2	33393	33392	0.67	0.00	0.00
3	140000	140059	-58.50	-0.04	0.04
4	150000	150065	-64.70	-0.04	0.04
5	215000	215354	-354.00	-0.16	0.16
6	400000	399239	761.40	0.19	0.19
7	500000	503876	-3875.70	-0.78	0.78
8	500000	500449	-448.50	-0.09	0.09
9	963500	963144	355.60	0.04	0.04
10	1000000	1000177	-177.00	-0.02	0.02
11	1566094	1572575	-6481.00	-0.41	0.41
12	1600000	1599210	790.00	0.05	0.05
13	2000000	2000250	-250.00	-0.01	0.01
14	5500000	5500851	-851.00	-0.02	0.02
15	120000	119784	216.20	0.18	0.18
16	4720000	4719782	218.00	0.00	0.00
17	33312	33320	-7.94	-0.02	0.02
18	400000	397732	2268.50	0.57	0.57
19	950000	944340	5660.40	0.60	0.60
20	20000	20015	-14.82	-0.07	0.07
21	30800	30794	5.81	0.02	0.02
22	89800	87524	2276.37	2.53	2.53
23	89800	89605	194.96	0.22	0.22
24	100000	99951	49.21	0.05	0.05
25	195600	195500	100.40	0.05	0.05
26	200000	200030	-29.70	-0.01	0.01
27	5288	5197	91.43	1.73	1.73
28	45000	44978	22.18	0.05	0.05
29	50000	49997	3.25	0.01	0.01
30	4000000	3999614	386.00	0.01	0.01
31	3000	3006	-5.59	-0.19	0.19
32	500000	501869	-1868.80	-0.37	0.37
33	745167	744838	329.40	0.04	0.04
34	2000000	1995970	4030.00	0.20	0.20
35	975500	976201	-701.38	-0.07	0.07
MPE		0.12			
MAPE		0.26			

8.5 Multiple Regression Model

In the absence of previous quantitative approach to the research problem, to test the usefulness of the ANN model further, a multiple regression (MR) model was developed to serve as a baseline for comparison of the ANN model performance. This technique is chosen because it is commonly employed in construction management research and it is a familiar modelling technique to many professionals in the industry.

In developing a MR model, the independent variables are regressed upon the dependent variable. The regression model is represented as an equation based on the linear (or non-linear) relationship between the dependent variable and two or more independent variables plus an error term. The equation is constructed from simultaneous assessment of the influence of the independent variables upon the dependent. The model usually take the general form:

$$Y = a + b_1X_1 + b_2X_2 + \dots\dots + b_kX_k + e$$

Where, Y = dependent variable;

a = intercept on y-axis; Xs = independent variables;

b_k = regression coefficient for k independent variables; and

e = the error term.

The estimated regression coefficient, b_k, is used to measure the amount of changes in Y due to the influence of changes in X_k (Lewis-Beck, 1980; Tabachnick & Fidell, 1983, and Chatterjee & Price, 1991).

As a requirement of the technique, the normality distribution of the data were examined and transformation applied where necessary to meet the normality assumption of the regression modelling techniques. The development and analysis of the MR model were carried out on PC using the statistical package for social sciences (SPSS) software.

The regression models of the total cost of variations was developed and tested using the same sets of data used in the training (thirty-five cases) and testing (ten cases) of the ANN model described above. The initial model included all the 22 factors. However, to simplify the model, "backward stepwise" procedure of the spss program was used. This procedure uses probability of F-value to determine the factor(s) that influenced most the independent variable, that is the total cost of variations.

Based on this approach a number of model were developed and the best model selected, using the 'goodness of fit', which demonstrates how well the model actually fits. To determine the goodness of fit for each of the models, the coefficient of multiple determination, R^2 and the adjusted coefficient of multiple determination, R_a^2, both of which measure the proportional reduction variability, were calculated and examined. Based on these criteria, the best model selected included only five of the factors with the probability F-value of ≤0.05. Table 8.4 summarised the parameter coefficients and the t-values for the selected model. The model can be expressed as:

$$\mathbf{lnTCV = 8.233 - 0.148CC2 + 2.022PC3 - 0.020PC4 + 0.099DC2 + 0.015PF2 - 0.475PF4 + 0.482EF1}$$

where : InTCV = natural log of total cost of variations

CC2 = client experience

PC3 = project complexity

PC4 = project total duration

DC1 = design duration

PF2 = construction duration

PF4 = number of subcontract

EF1 = economy factor

Of the 22 factors, only 7 were included in the final model: client experience, project complexity, project duration, design duration, construction duration, number of subcontracts and the economy factor. The seven factors accounted for 84% of the variance in the total cost of variations.

The model performance results are summarised in Table 8.4. The table shows the quantitative analysis of the model prediction accuracy based on the modelling data. As shown in the table, the mean, percentage and absolute percentage, errors of the model is 30 and 56 respectively.

Table 8.4: MR model performance results

Project	Total cost of variations	MR Prediction	Error	PE	APE
1	25000	25844	-844	-3.38	3.38
2	33393	34427	-1034	-3.10	3.10
3	140000	141028	-1028	-0.73	0.73
4	150000	150916	-916	-0.61	0.61
5	215000	215163	-163	-0.08	0.08
6	400000	400191	-191	-0.05	0.05
7	500000	499216	784	0.16	0.16
8	500000	505673	-5673	-1.13	1.13
9	963500	960477	3023	0.31	0.31
10	1000000	1003208	-3208	-0.32	0.32
11	1566094	1568120	-2026	-0.13	0.13
12	1600000	1596428	3572	0.22	0.22
13	2000000	1990779	9221	0.46	0.46
14	5500000	5506302	-6302	-0.11	0.11
15	120000	115004	4996	4.16	4.16
16	4720000	4706355	13645	0.29	0.29
17	33312	15859	17453	52.39	52.39
18	400000	426034	-26034	-6.51	6.51
19	950000	979728	-29728	-3.13	3.13
20	20000	55943	-35943	-179.72	179.72
21	30800	1297	29503	95.79	95.79
22	89800	92052	-2252	-2.51	2.51
23	89800	116573	-26773	-29.81	29.81
24	100000	13642	86358	86.36	86.36
25	195600	162209	33391	17.07	17.07
26	200000	158949	41051	20.53	20.53
27	5288	-48958	54246	1025.83	1025.83
28	45000	131084	-86084	-191.30	191.30
29	50000	6607	43393	86.79	86.79
30	4000000	4159035	-159035	-3.98	3.98
31	3000	3815	-815	-27.17	27.17
32	500000	444232	55768	11.15	11.15
33	745167	312230	432937	58.10	58.10
34	2000000	1847039	152961	7.65	7.65
35	975500	546338	429162	43.99	43.99
MPE			30.21		
MAPE			56.14		

8.6 Results of Comparative Study of ANN and MR Models

The summary of forecasting performances of the two models is shown in Table 8.5. It can seen that, for the same data used in developing the models, the ANN predictive abilities are stronger than that of the MR. The improvement of predictive capabilities of ANN compared with MR range from 100 percent to 0.8 percent with an improvement mean of 54 percent.

Table 8.5: Comparative study results of ANN and MR models performances

Project	Total cost of variations	MR % error	ANN % error	Improvement*
1	25000	3.38	0.08	97.6
2	33393	3.1	0	100.0
3	140000	0.73	0.04	94.5
4	150000	0.61	0.04	93.4
5	215000	0.08	0.16	-100.0
6	400000	0.05	0.19	-280.0
7	500000	0.16	0.78	-387.5
8	500000	1.13	0.09	92.0
9	963500	0.31	0.04	87.1
10	1000000	0.32	0.02	93.8
11	1566094	0.13	0.41	-215.4
12	1600000	0.22	0.05	77.3
13	2000000	0.46	0.01	97.8
14	5500000	0.11	0.02	81.8
15	120000	4.16	0.18	95.7
16	4720000	0.29	0	100.0
17	33312	52.39	0.02	100.0
18	400000	6.51	0.57	91.2
19	950000	3.13	0.6	80.8
20	20000	179.72	0.07	100.0
21	30800	95.79	0.02	100.0
22	89800	2.51	2.53	-0.8
23	89800	29.81	0.22	99.3
24	100000	86.36	0.05	99.9
25	195600	17.07	0.05	99.7
26	200000	20.53	0.01	100.0
27	5288	1025.83	1.73	99.8

Project	Total cost of variations	MR % error	ANN % error	Improvement*
28	45000	191.3	0.05	100.0
29	50000	86.79	0.01	100.0
30	4000000	3.98	0.01	99.7
31	3000	27.17	0.19	99.3
32	500000	11.15	0.37	96.7
33	745167	58.1	0.04	99.9
34	2000000	7.65	0.2	97.4
35	975500	43.99	0.07	99.8
	Mean improvement = 54.03%			

* $improvement = \left(\frac{MR - ANN}{MR}\right)100$

The model predictive capabilities were tested further using the independent data set aside earlier. The results of the two models forecasts of the total cost of variations for the test data set are summarised in Table 8.6 below. The MAPE values for the ANN and MR models were 3.3 percent and 7.4 percent respectively. Although both models were able to produce accurate forecasts, less than 10 percent, but ANN model performed outstandingly better then the MR model with an average improvement of 37 percent. This result clearly demonstrates not only the abilities of artificial neural networks as a better modelling technique but also justifies its use as the main research modelling technique.

Table 8.6: ANN and MR models test results

Project	Total cost of variations	MR % error	ANN % error	Improvement
1	350000	5.6	0.8	86.6
2	963499	11.3	0.0	100.0
3	590000	2.0	0.1	92.8
4	22000	10.2	2.0	80.7
5	50000	4.2	0.2	94.8
6	100000	1.3	15.5	-1072.0
7	12000	9.0	7.8	13.5
8	177275	13.4	0.1	99.0
9	10000	16.2	6.2	61.7
10	1800000	0.4	0.1	68.6
MAPE =		7.4	3.3	
Mean improvement =		37.4		

8.7 Results Discussion

The low MAPE values (less than 10%) obtained by the two models imply that construction process factors can be used as realistic inputs for modelling variations' contingency. This finding provides further justification for the research initial premise and the conclusions of previous research findings (Bromilow, 1969, 1970, 1971; Bromilow and Henderson, 1971) that variations are an inevitable part of the construction process, and a major influence on project performance, decisions to order them would be influenced by the construction process factors.

In relative terms, however, the ANN model generated about half of the prediction error of the MR model. This can be attributed to the nature of the ANNs models. They are designed to capture and learn the non-linear relationship between the inputs and output variables rather than using a presumed linearity to fit a global equation to the data as in the case of MR. Since the magnitude of variations on construction projects is generally influenced by construction process factors which often lead to success or failure of the project, the adoption of a non-linear representation of the magnitude of variations and the factors should well be a more realistic and accurate one rather a presumption.

However, the results does not imply that MR as modelling technique do not have their merits. They are essentially causal method which allow the relationship the dependent and the independent variables to be analysed and explained. The absence of this simple explanatory capability without complex mathematical computation in artificial neural network systems has made the method sometimes being termed 'black box' method. But recent development in the neural computation has led to the development of few network simulation packages (such as 'neuroSolution' used in the research) that can perform causal analysis.

Comparing the two models' predictive capability with present conventional arbitrary approach to variations' contingency forecast employed in the industry, the model performance results support the criticism of the conventional approach. As Yeo (1990) suggests the approach is overly simplistic and unrealistic. It also lack, a formal or informal methodology that may enable the determined contingency and the inputs factors to be justified or explained.

Among the twenty-two construction process factors theoretically identified and investigated, ten were found to be significantly relevant to the modelling of the total cost of variations on construction project. Those that were not included in the model are: project type and duration, designers' experience, duration and percentage of design completed, method of procurement and type of contract, method of tender. Others are; contractors' experience and construction duration, and the environment social factor.

Although, these factors were theoretically identified to influence magnitude of variations but their significance were disputed by the network and the statistical analysis. However, this does not necessarily reduce the theoretical importance of these factors. For example, the method of procurement and type of contract are thus found to be less significant but they determine the project organisational setup and, define and allocate responsibility of each of the organisations involved within the particular project. They also outline the procedure for ordering and payment for variations as well as how to resolve any claims or disputes that may arise as a result of the variation. In other words, the competence of the project management in successfully managing variations has to rely upon many of these factors.

8.8 Summary

This chapter has demonstrated the application of artificial neural network to development of a model to predict the variations cost contingency. The model used analysed construction process factors, theoretically identified and investigated as influencing the magnitude of variations, as inputs attributes of the model. Comparing the developed model with a multiple regression based model, developed to provide a baseline, the pattern-recognition capabilities and predictive abilities of artificial neural network models is demonstrated.

There are several complex factors that influence variations, but it is impossible to develop a simple model that will incorporate all the factors and at same time maintaining the meaningful predictive consistency of the model. The network model therefore, incorporated only ten of the construction process factors found more significant without sacrificing the model's predictive abilities. The ten factors were:

- Client characteristics: client type, and client experience;
- Project characteristics: project size, and project complexity;
- Tendering procedure: type of tender documentation;
- Production process: adequacy and availability of information, and number of subcontracts;
- Environment factors: economy, political, and technology.

The model performance results show that magnitude of variations can be quantitatively predicted with more realistic accuracy than the present arbitrary allocation approach employed in practice. The structured methodology of the model approach provide realistic justification and explanation for the predicted amount, which in turn, would aid the control of variations when they become unavoidable during the construction. With adequate and realistic contingency, negotiation of their cost would be facilitated, and reduce the magnitude and frequency of claims and disputes often caused by variations.

CHAPTER NINE

THE MODEL VALIDATION

9.1 Introduction

In chapter seven, the relationship between variations and a significant number of construction process factors was established. Subsequently, an artificial neural network model based on the established relationship was developed for predicting variations' contingency as reported in chapter eight. The procedure for validation of the consistency of accuracy and sensitivity of the model to changes of the input factors are described in this chapter. The chapter also describes the comparative study of the model's performance quality against the traditional practice of contingency allocation, and the model application benefits.

9.2 Model Performance Validation Procedure

The term 'validation' is often a prominent feature in the literature on education, psychology, marketing and research methodology. However, there is no unique definition of the term, although it is generally understood to be related to model testing. O'Keefe et al (1987), defined validation as process of checking the appropriateness of a model to help tackle real world problems as seen from the point of view of those involved in the model's creation and use. To economists or social scientists, who exploit modelling to represent or explain a phenomena or relationship in a real world, this definition may be accurate.

Thus validation ascertains how a model will perform in practice, however, in a research where objectivity is sought and variance is to be avoided, validation also investigates the theoretical basis on which the model is based. Therefore, validation as a process determines whether the model is properly developed, and can perform at an acceptable level of performance in terms of accuracy and efficiency. On this basis, a three step procedure was adopted for the validation of the model.

First, using an independent data, the consistency of the model performance accuracy is tested. This test is concerned with whether the model is capable of maintaining its predictive level of accuracy on the new set of data. If the model is properly trained, its accuracy should be consistent enough to be accept or rejected. Second, the validity of the research hypothesis in relation to the model's performance accuracy was validated. Based on statistical analysis, the research hypothesis developed in chapter five tested and rejected. Finally, the sensitivity analysis of the model to changes of its parameters were evaluated. A model should be sensitive enough to detect subtle change in the input data, thus, providing an index that can be use to justified the prediction and decision making what if analysis.

9.2.1 Validity of the ANN Model's Consistency

Artificial neural network models learns it knowledge from training data. Testing the model on the training data would only reflect how well the knowledge fits the data which is not a reliable estimate for unseen data independent of the training set. For this reason, the validation data was collected after the model has been developed. Data from twelve projects were collected and used for validation (see Table 8.2 for the model configuration).

The same methodology used to collected the training data, as described in detail in Chapter five, was adopted for collection of validation data set. However, unlike the initial questionnaire, part two of the validation questionnaire elicited information from the project relevant to the model's parameters. The questionnaire can be found in appendix B.

The forty-five organisations that provided the training data were contacted by telephone or letter for further assistance. Of the forty-five, only fifteen organisations (3 clients, 4consultants, and 5 contractors) offered to participate further. The designed validation questionnaire were sent to the project manager, quantity surveyor, contract manager or executive with adequate knowledge of the chosen project for completion. Out of the fifteen completed questionnaire, three were unused because they were incomplete. The Twelve projects varied in type and size as summarised in Table 9.1. The input parameters, measured from the twelve projects, are given in Table 9.2.

Figure 9.1 shows the actual total cost of variations plotted against the predicted values. The variances between the actual and the model's predicted values were calculated to determine the error associated with each prediction. The error range was established for the whole data set and the mean standard error calculated to determine the model's accuracy and its consistency compared with the acceptable level of accuracy in the construction industry for the model of this nature.

Table 9.1: Validation projects by types and sizes

Proj. Cost Range	Office	Education	Residential	Others (leisure and retail)
Less £1m		-	2	-
£1 - 5m	2	2	1	2
£5 - 15m	1	1	-	-
£15 - 25m	-	-	-	-
£25 - 50m	-	-	-	-
Over £50m	1	-	-	-
Total	4	3	3	2

Table 9.2: Inputs parameters

Project type	cc1	cc3	pc2	pc3	tp2	pf4	pf3	ef1	ef3	ef4
R	1	1	1	1	4	2	1	3	3	2
R	1	1	1	1	1	2	1	3	2	1
O	2	3	1	2	1	2	2	2	1	2
O	2	3	2	1	3	1	2	3	1	1
E	1	1	2	2	1	3	2	2	3	2
OF	2	5	2	2	1	2	1	2	2	1
R	1	1	2	1	3	2	1	3	2	1
OF	2	4	2	2	1	2	2	2	1	2
E	2	5	3	2	1	1	3	1	1	2
E	1	1	2	2	1	2	2	3	3	2
OF	2	5	6	3	2	3	3	2	1	3
OF	1	2	3	3	1	1	1	2	2	2

R= residential, O= others
E= education, and OF= office

The summary of the results is shown in Table 9.3. With exception of project no 2 and 5, the model's prediction errors were less than 5%. From the table, 83 percent of the projects' total cost of variations were predicted with errors below 5 percent. These two projects with large prediction errors were built by two public clients through design and build, and management contracting procurement methods respectively. The large prediction errors observed on these projects can be explained by the fact that very few of the training cases used to developed the model were management contracting and design and build projects (4% and 16% respectively). The ability of an artificial neural network model to properly learn and generalise in order for its predictions to be within the required accuracy, needs the model be trained on an adequate number of various project types. However apart from this limitation, with an overall average prediction error of 24 percent, the model's performance is well within the acceptable level of accuracy (Blok, 1982; McCaffer,1975). This validated the research hypothesis that variations' contingency can be predicted, quantitatively, with better accuracy than the existing traditional approach.

Fig. 9.1: Validation test results

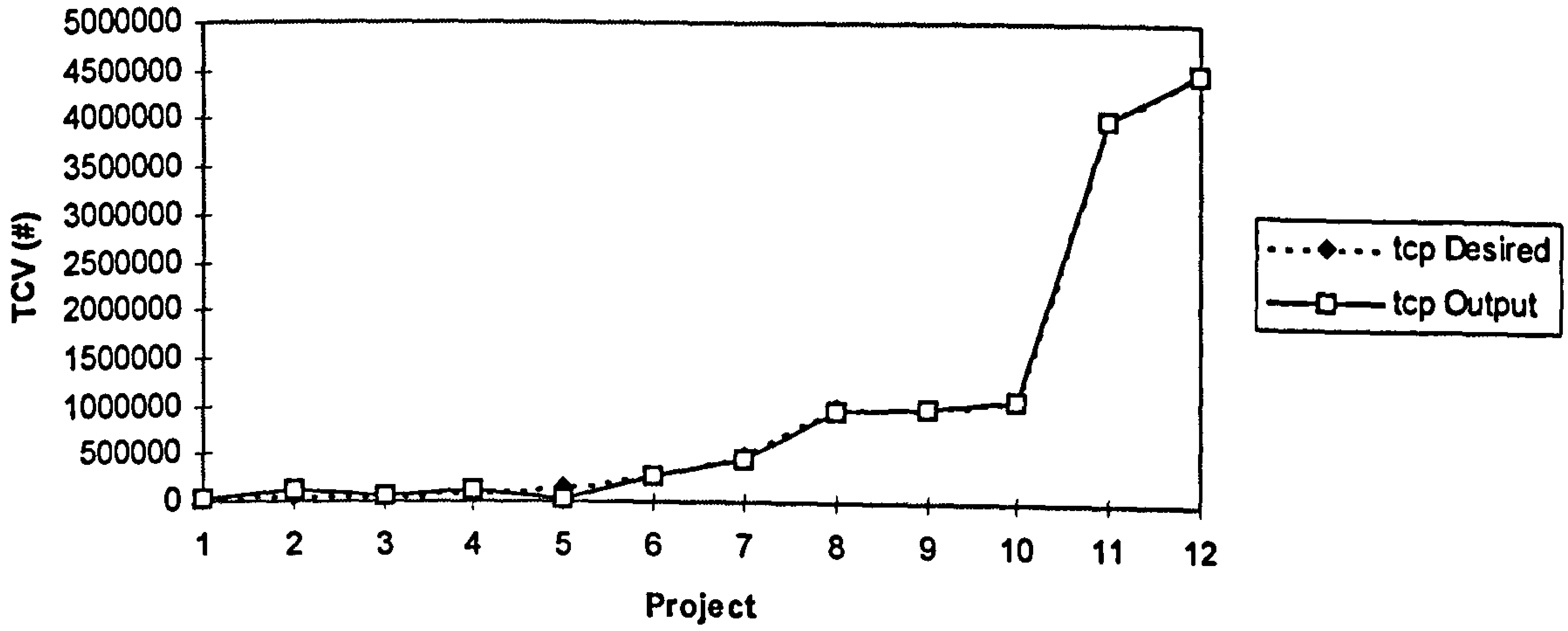


Table 9.3: Validation results

Project	Actual TCV (£)	ANN prediction (£)	Error	PE (%)	APE (%)
1	22554	22554	0	0.00	0.00
2	52000	130362	-78362	-150.70	150.70
3	65000	52676	12324	18.96	18.96
4	100000	121231	-21231	-21.23	21.23
5	150000	22554	127446	84.96	84.96
6	275000	273735	1265	0.46	0.46
7	475000	455859	19141	4.03	4.03
8	975500	969089	6411	0.66	0.66
9	1000000	1000373	-373	0.04	0.04
10	1084184	1081523	2661	0.25	0.25
11	4000000	4006084	-6084	0.15	0.15
12	4500000	4500001	-1	0.00	0.00
MPE			-5		
MAPE			24		

To validate the integrity of the model's consistency, chi-square statistical analysis was used. Intuitively, if the TCV on those projects can be predicted with a mean error, as observed, closer to that on the training data (see Table 8.8), then the model has learned the common characteristics of the construction projects to predicts consistently. To test this proposition, the chi-square (χ^2) is calculated by:

$$\chi^2 = \sum \frac{(p_e - p_o)^2}{p_o} \quad \text{where } p_o = \text{actual TCV, and}$$

$$p_e = \text{predicted TCV}$$

From Table 9.4, therefore, the χ^2 value is 1845.70. To test χ^2, assume a significant level of 0.01 with 12 degrees of freedom, $\chi^2_{0.01}$ value (from statistical Table) is 3.571. Since our calculated χ^2 is greater than 3.571, we can conclude that the model is consistent.

Table 9.4: Chi-square test of model's consistency

Project	Actual TCV (Pe)	Predicted TCV (Po)	Pe -Po	$(Pe - Po)^2$
1	22554	22554	0	1.11E-02
2	52000	130362	-78362	6.14E+09
3	65000	52676	12324	1.52E+08
4	100000	121231	-21231	4.51E+08
5	150000	22554	127446	1.62E+10
6	275000	273735	1265	1.60E+06
7	475000	455859	19141	3.66E+08
8	975500	969089	6411	4.11E+07
9	1000000	1000373	-373	1.39E+05
10	1084184	1081523	2661	7.08E+06
11	4000000	4006084	-6084	3.70E+07
12	4500000	4500001	-1	2.50E-01
	$\sum p_e = 12699238$			$\sum p_e = 2.34E+10$

9.2.2 Validity of research hypothesis

The primary and secondary hypotheses of the research were stated in chapter. The first of these, based on the relationship between variations and construction process factors, was tested in chapter six. The second hypothesis derived from the first in relation to the research aim, is that:

"Given the relevant factors, the magnitude of variations on a construction project can be predicted with a significant accuracy".

ANN as modelling technique is, to an extent, non-statistcal in nature, which means, however, in order to test the validity of this hypothesis, a Spear-man coefficient of rank correlation (r_s) is used. The model test results on the validation data set are given shown in Table 9.3 above. If the model prediction performances are accurate, the predicted values and the actual values should be significantly correlated, that is more than 0. Therefore, the null and alternative hypothesis to be tested can be stated as follows:

$$H_0 : \mu_d = 0$$
$$H_A : \mu_d > 0$$

The calculation of the Spear-man coefficient of rank correlation was carried out as follows:

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$ where d_i = difference between ranks;

n = number of pair of values (12)

As calculated in the last column of Table 9.5, the value of $\sum d_i^2$ is 25.92 (calculated tied value is added to value $\sum d_i^2$). Therefore,

$$r_s = 1 - 0.0906 = 0.909$$

The r_s value indicate high correlation between the two sets of ranks. To test r_s assuming a 0.05 significant level, the critical values of $r_{0.05}$ for 12 degrees of freedom is 0.5804 (Conover, 1971). Since our calculated r_s is greater than 0.5804, we reject the Ho and conclude that the total cost of variations can be predicted with significant accuracy.

Table 9.5: Research hypothesis validity test results

Project	Actual TCV		Predicted TCV		d_i	d_i^2
(A)	Value (B)	Rank ©	Value (D)	Rank (E)	(F)	(G)
1	22554	1	22554	1*	0	0
2	52000	2	130362	5	-3	9
3	65000	3	52676	3	0	0
4	100000	4	121231	4	0	0
5	150000	5	22554	1*	4	16
6	275000	6	273735	6	0	0
7	475000	7	455859	7	0	0
8	975500	8	969089	8	0	0
9	1000000	9	1000373	9	0	0
10	1084184	10	1081523	10	0	0
11	4000000	11	4006084	11	0	0
12	4500000	12	4500001	12	0	0
						$\sum d_i^2 = 25$

Tied (t) $= t^2 - \frac{t}{12}$

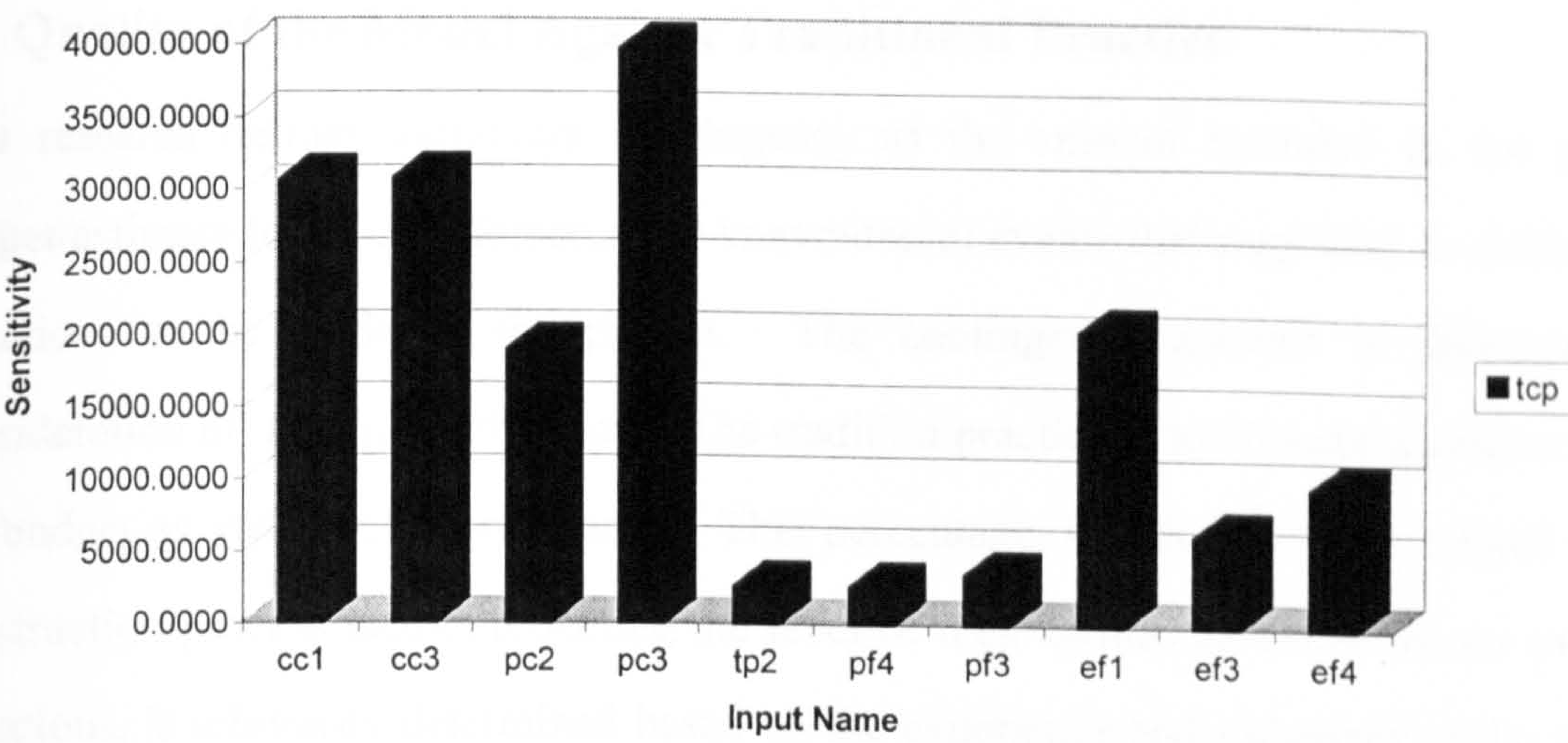
*Equal ranks (tied)

9.2.3 Sensitivity Analysis

In order to investigate the model's response to changes in the input factors, a sensitivity analysis was conducted. A quantitative model, as decision making tool, should be sensitive enough to detect changes in its input parameters as those changes will determine the variability in the predicted total cost of variations to be expected on the project.

To determine this variability, the first input factor was varied between its mean +/-50 times number of its standard deviation while all other input factors were held constant at their respective means. The model output is computed each time the factor was varied above or below the mean. This process was repeated for each input factors in turn (see Appendix E for the plotted graphs for each input factors showing the output(s) over the range of the varied input factor). It is interesting to note that the relationship between number of these input factors and the output are non-linear. This feature reinforces the justification for using neural network which are capable of modelling complex non-linear relationship between inputs and output variables. Next, the variability was calculated by dividing each output standard deviation by the standard deviation of the input factor which was varied to create the output. Figure 9.2 summarised the results.

Fig. 9.2: Sensitivity About the Mean



Having determined the standard variability, the values were converted into percentage. Table 9.6 shows the summary of the conversion. The Table shows the indication and ranking of the ten input factors according to their influence on the output. For example, by increasing the complexity of a project, will result in 24% increase in the total cost of variations to be expected on the project. This results can also be transformed, as will be demonstrated later, into a decision tree to explain or justify the model's predictions.

Table 9.6: Model sensitivity analysis

Sensitivity	TCV	%effect	Rank
cc1	30761	18.53	3
cc3	30891	18.61	2
pc2	19029	11.46	5
pc3	39793	23.97	1
tp2	2644	1.59	10
pf4	2646	1.59	9
pf3	3547	2.14	8
ef1	20482	12.34	4
ef3	6385	3.85	7
ef4	9808	5.91	6
Total	165988	100	

9.3 Quality of the Model Against Traditional Practice

This research defines variations' contingency as the amount included in the project budget/estimate to cover unforeseen (or unavoidable) events that may lead to ordering of variations to be made to the project. The contingency amount is determine by consideration of a number of factors. The tradition practice is to allocate a percentage of the budget as variations' contingency. This percentage, which should be related to the construction process factors reflecting the level of their influences on decisions to order variations, is arbitrarily determined based on the experience and judgment of the project management. However, this approach has been found and criticized to be overly simplistic and unrealistic in many research studies (Blok, 1982; Yeo, 1990; Ranasinghe, 1994). The validity of this findings is the primary interest of this section.

Figure 9.3 shows the actual values of total cost of variations on the twelve projects plotted against the traditional determined amounts. The method prediction errors range between 0 and 100 percents with a mean percentage error of 77 percent. This variances evidence enough to support the previous research findings of the inaccuracy of the traditional practice. Further analysis of the results using a Spear-man coefficient of rank correlation, as applied in section 9.2.2 above, confirmed this indication. The results of the test is given in Table 9.7 below. The results were tested further for any association between the pair values as a means of testing the reality of the traditional method. The calculated rank correlation, r_s is only 0.42 compare to $r_{0.05}$ value of 0.4965. These results indication support the previous research findings of Yeo (1990) and Ranasinghe (1994) that the traditional method is over simplistic and unrealistic in its prediction of contingency.

To investigate the differences in performance accuracy of the traditional practice and the ANN model, the relative influence of the factors in relation to the two methods predictions were compared. Assuming that allocation of contingency in practice is related to those factors, then there should be a strong association between the ranking of the factors by the ANN model and the Professionals in the industry. The twelve respondents were asked to rate, on 10-point scale, the importance of the ten factors identified as influencing the magnitude of variations or decision to order variations. The total scores for each factor is calculated and converted into a relative index used to rank the factors according to their degree of importance. The ranking results of the ANN and the traditional methods were compared. The results of the comparative study are given in Table 9.8. As shown in the Table, there was no association between the ranking of these factors between the professionals compared to the objective reality of the association that exist between the factors and the magnitude of variations as elicited by the ANN model.

Fig. 9.3: Actual TCV against Traditional predictions

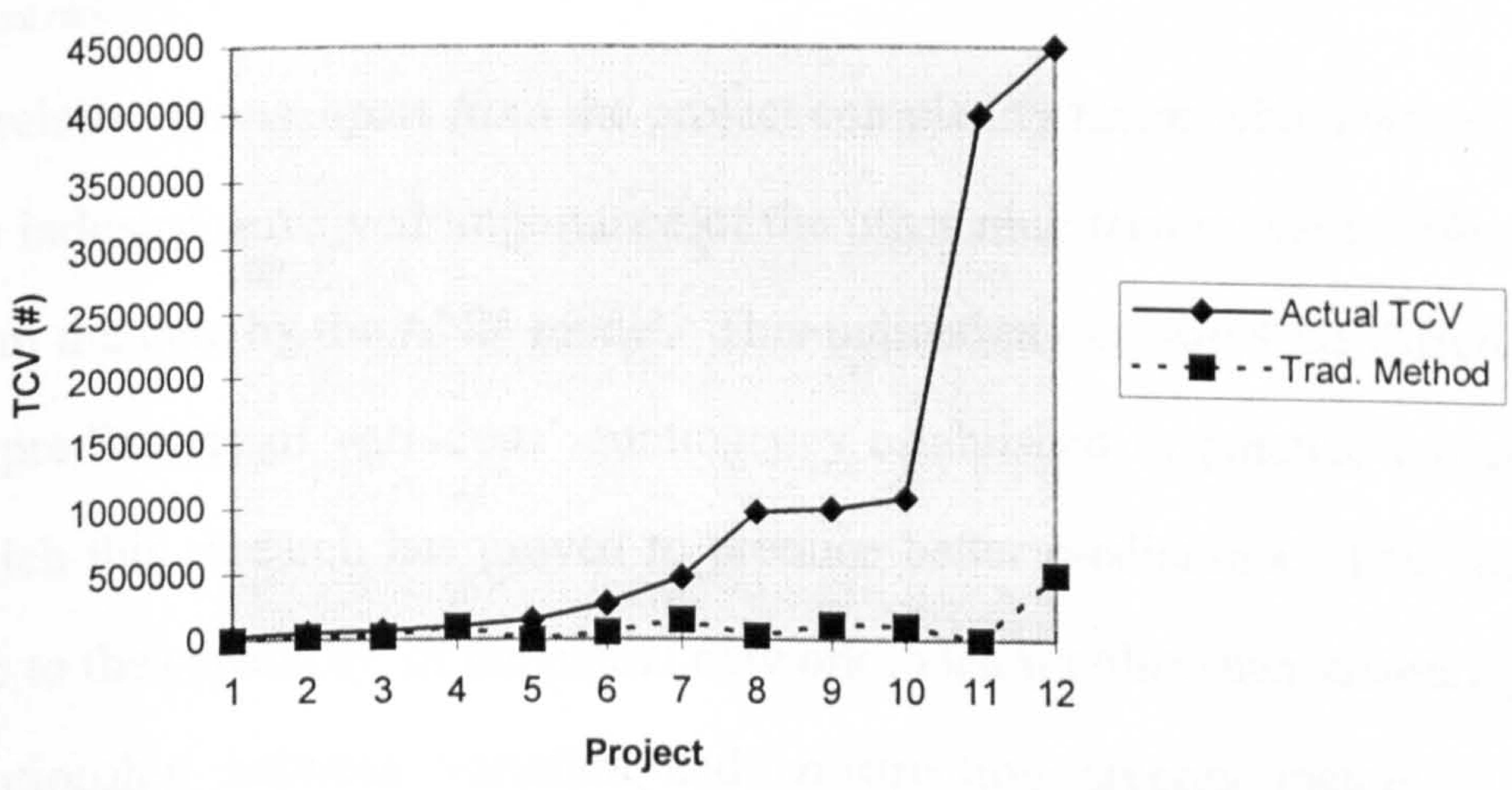


Table 9.7: Accuracy of test results of traditional method

Project (A)	Actual TCV Value (B)	Rank ©	Conventionally Predicted TCV Value (D)	Rank (E)	d_i (F)	d_i^2 (G)	APE (%)
1	22554	1	0	1*	0	0	100
2	52000	2	27200	5	-3	9	47.7
3	65000	3	25000	4	1	1	61.5
4	100000	4	100000	8	-4	16	0
5	150000	5	0	1*	4	16	100
6	275000	6	60000	7	-1	1	78.2
7	475000	7	150000	11	-4	16	68.4
8	975500	8	35000	6	2	4	96.4
9	1000000	9	120000	10	-1	1	88
10	1084184	10	107000	9	1	1	90.1
11	4000000	11	0	1*	10	100	100
12	4500000	12	500000	12	0	0	88.9
						$\sum d_i^2$ 165	
MAPE							76.6%

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} = 0.42$$

$r_{0.05} = 0.4965$

*Equal rank

In relative terms, apart from the project complexity factor which was equally ranked first, the industry perceived importance of the other nine factors were different to that learned from the data by the ANN model. This indication explained the difference in the quality of predictions of variations' contingency established in practice compared to the ANN which this research has proved to produce better predictions. This indication is largely due to the capability of the neural network to learn rather than assuming the degree of the relationship between variation and construction process factors of various type of projects. The identification of this relationship is the central part of the model prediction ability. Only when this relationship is clearly understood can better contingency be determined.

Table 9.8: Results of the comparative study

Factor	Industry's perception	ANN model	d_i	d_i^2
Client type	5	3	2	4
Client experience	3	2	1	1
Project size	9	5	4	16
Project complexity	1	1	0	0
Tender documentation	6	10	-4	16
Adequacy of information.	2	8	-6	36
Number of sub-contract	8	9	-1	1
Economy	4	4	0	0
Politic	10	7	3	9
Technology	7	6	1	1
				$\sum d_i^2 = 84$

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} = 0.49$$

$r_{0.05} = 0.6833$

9.4 Application of the Model

The ultimate rationale for developing the artificial neural model was to be able to predict variations' contingency allowance to be added to the project estimate. This involved identifying a number of factors in relation to the proposed project. The contingency could then be predicted based on these factors.

The use of the model to achieve this objective, can be implemented through a purposely designed work-sheet template in Mcrosoft Excel programme in which the model is embedded using the programme's OLE (object linking and embedding) facility. The whole process involves the following steps:

1. Fill in the data information sheet ticking relevant attributes values relating to the proposed project's characteristic (a typical sheet is shown in Table 9.9).

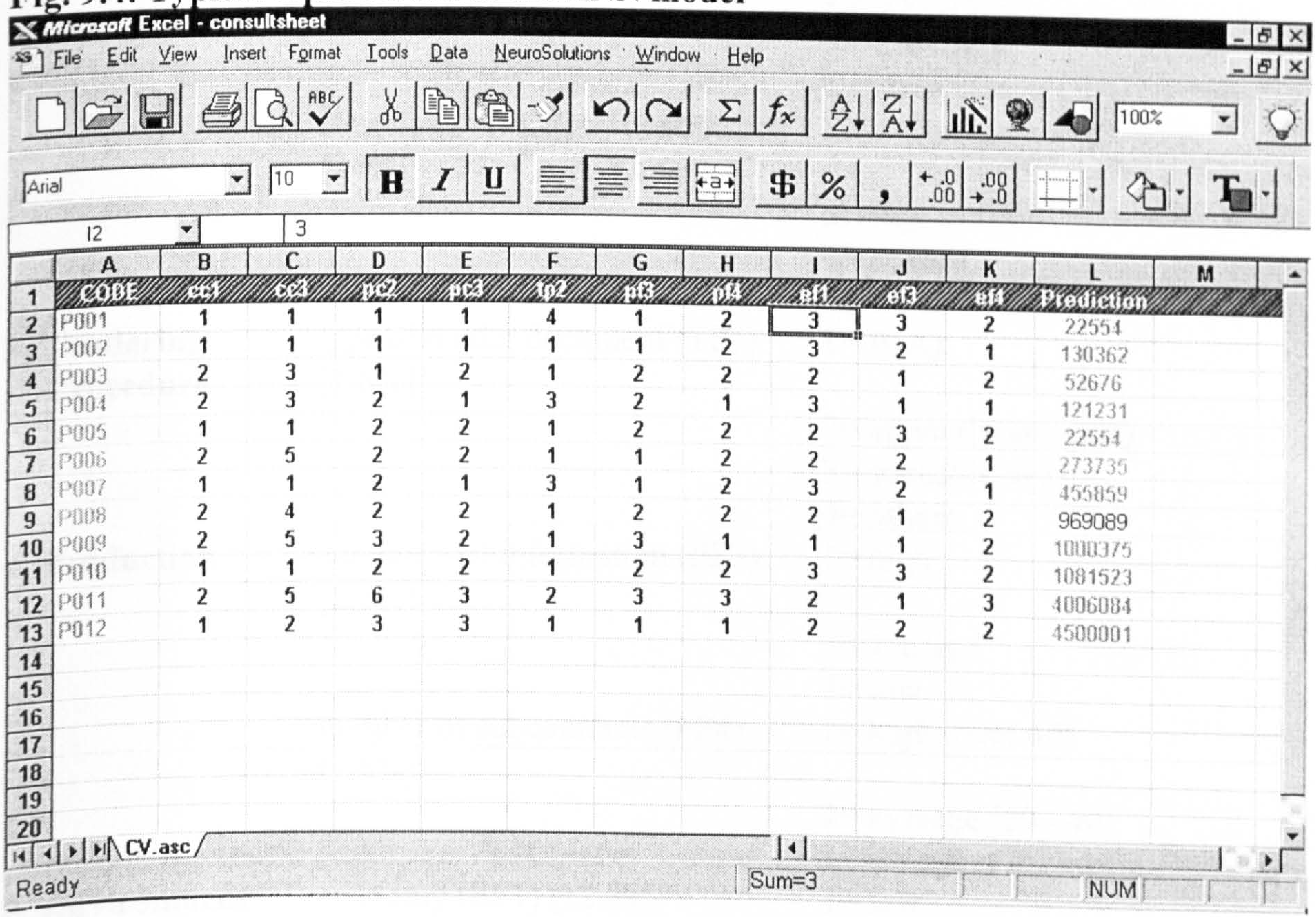
2. Input the values into the work-sheet template in Excel.

3. Invoke the test command through the 'Neurosolution' menu in the tool bar. The model translate the user provided information into input values for the model.

4. The model then reproduces the work-sheet with its predicted value given in the prediction column.

Once the input are entered into the work-sheet by the user, the model consultation process will take approximately 5-7 seconds to come up with the response. Figure 9.4 present a consultation session with the model. The figure shows inputs information for the twelve projects used for validation with the model predictions given in the last column.

Fig. 9.4: Typical input screen of the ANN model



CODE	cc1	cc3	pc2	pc3	fp2	pf3	pf4	ef1	ef3	ef4	Prediction
P001	1	1	1	1	4	1	2	3	3	2	22554
P002	1	1	1	1	1	1	2	3	2	1	130362
P003	2	3	1	2	1	2	2	2	1	2	52676
P004	2	3	2	1	3	2	1	3	1	1	121231
P005	1	1	2	2	1	2	2	2	3	2	22554
P006	2	5	2	2	1	1	2	2	2	1	273735
P007	1	1	2	1	3	1	2	3	2	1	455859
P008	2	4	2	2	1	2	2	2	1	2	969089
P009	2	5	3	2	1	3	1	1	1	2	1000375
P010	1	1	2	2	1	2	2	3	3	2	1081523
P011	2	5	6	3	2	3	3	2	1	3	4006084
P012	1	2	3	3	1	1	1	2	2	2	4500001

Table 9.9: Typical data information sheet

Factors Category	Factors	Coding Scheme	Tick
1. Client Characteristics	type (CC1) [18.5%]	1= public	
		2= private	
	experience (CC2) [18.6%]	1= high	
		2= average	
		3= low	
2. Project Characteristics	size (PC2) [11.5%]	1= less than 1moffice	
		2 = 1 - 5m	
		3 = 5 - 15m	
		4 = 15 - 25m	
		5 = 25 - 50m	
		6 = over 50m	
	complexity (PC3) by cost/month [24%]	low = less than 140k/mon	
		average = 140 - 450k/mon	
		high = over 450k/mon	
3. Tendering Procedure	type of tender document (TP2) [1.6%]	1= BOQ	
		2= approximate BOQ	
		3= schedule of rate	
		4= others	
4. Production	adequacy of information (PF3) [2.1%]	1= high	
		2= average	
		3= low	
	number of subcontracts (PF4) [1.6%]	1= high (over 40)	
		2= average (20 - 40)	
		3= low (less than 20)	
4. Environment Factors	economy (EF1) [12.3%]	1= low	
		2= average	
		3= high	
	political (EF3) [3.9%]	1= low	
		2= average	
		3= high	
	technology (EF4) [5.9]	1= low	
		2= average	
		3= high	

Percentage effect in [ ]

It should be emphasised here that this thesis only sought to develop a structured methodology of establishing a contingency for variations. The applicability of the model is, therefore tested on this basis. However, while the model is developed to be use as a predictive tool, it can also aid in providing an explanation for the predicted amount, and 'what-if' of those factors that can be control by the decision maker. An example is use to illustrate this.

Consider case study project number 4 for an example. On the bases of the input factors the model predicted the contingency to be £121231. What if the project complexity can be reduced, and the adequacy of information improved? The effect on the predicted value can be calculated as follows:

■ the predicted value =	£ 121231.00
■ plus complexity @ 24% =	-£29,095.44
■ plus adequacy of information @ 2.1 =	-£2,545.85
New contingency value =	**£89,589.71**

With reduction in complexity of the project, and more adequate information, the contingency amount can reduce by 26%. This analysis provide the decision make to evaluate their options as well as the effect of the factors within their control.

9.5 The Professionals' Views of the Model

It was interesting to know how the professionals' reactions, in particular to the model's performance accuracy. To achieve this, the results of the model were discussed with six of the twelve respondents which consisted of two, clients, consultants and contractors.

The clients expressed their agreement with the model, thus they were surprised that, with the existing research knowledge available to the industry, the traditional approach is still being used in forecasting the contingency. With better accuracy, they believed that project cost performance could be improved. Given the structured approach of the model, the impact of any variation will be given more consideration before it is order. Also, with better forecast of contingency, cost certainty of the project earlier would improve.

Consultants, thus, were very surprised by the level of accuracy of the model but, remained doubtful whether knowing the cost magnitude of variations would actually reduce variations. However, they are in general agreement that with an adequate contingency, the time and cost of negotiation of variations during the construction of the project would be reduced. This will in turn lead to reduction in disruption and disputes cause by variations. The reservation as to the use of the model, however, remained. The reason given is mainly based on whether the client would be ready to accept the estimate and go ahead with the project without demanding that the budget be reduced in which case, the contingency is often the prime target for cost cut.

The contractors too agreed with the model and expressed no surprise at all. They believed that variations are influenced by the identified factors, but the contingency allocations are not based on them but guessed by the project cost consultant. It is believed that if a proper contingency is establish before hand, negotiation of variations would be easy and quicker rather than the prolonged tactic of the project management because often, the contingency is spent before the project even gets off the ground. Furthermore contractors' perceive that the only way for the project manager (quantity surveyor) to guard against their own incompetence is to prolong negotiation and often refuse to agree to the cost or even whether the work is a variation.

9.6 Summary

The main objective of developing this model in chapter eight was to provide the project management with a tool that will assist in establishing a better and realistic contingency for variations which are inevitable. In validating the model, three criteria were adoted:

(i) to test the consistency of the model whether it can maintain its prediction accuracy in unknown situations and environment. This ability is very important if the model is meet the development objective.

(ii) to test the validity of the research hypothesis which was based on the overall aim of the research.

(iii) sensitivity analysis of the model to study the relative influences of the model input parameters on the model prediction. This very important for justification of the contingency amount.

The test results of these criteria have proved that the artificial neural network model, with high degree of accuracy, is not only consistent and accurate, within the acceptable limit, in predicting variations' contingency but also shown to be better than the current traditional approach employed in practice.

CHAPTER TEN

CONCLUSION AND RECOMMENDATIONS

10.1 Introduction

The research reported in this thesis set out to review and evaluate the construction project management of variations with the objectives; of identifying construction process factors influencing the magnitude of variations; and to develop a methodology for forecasting the contingency for variations. To achieve these objectives, construction project organisation and performance (focusing on the problem of variations) was first reviewed, along with risk and uncertainty management.

The construction industry must serve its clients to the best of its ability; organisation of the project and the construction process were central elements in achieving this objective. Unfortunately, the inability of the industry to meet this objective has been, for decades, a major concern. Previous investigations, including the report by Sir Michael Latham (1994), identified variations as a major problem in construction contributing to the inefficiency of the industry and cause of its client's dissatisfaction.

Variations were identified as unavoidable and necessary evil of construction, but a deeper understanding of their sources, nature and knowledge of factors influencing their occurrence will contribute to the existing knowledge and aid in the management and control of variations when they occur, hopefully turning this evil to an advantage.

The case study approach adopted allowed access to more detailed data. This allowed both analytical and quantitative generalisations to be drawn and used to meet the research aim and objectives. Therefore, this research study could be described as an exploratory, analytical and quantitative investigation of variations, including an explanation of the factors influencing their magnitude on construction projects.

Previous researchers, as reviewed earlier in chapter two, have identified and classified the sources and nature of variations. However, those research considered only one or two of the influencing factors, in isolation, in their attempt to examine their impact on performances. This research, however, identified all factors influencing the magnitude of variations, and quantitatively examined their influence on variations, and established the relationship between these factors and variations. This formed the basis for development of a quantitative model to predict the contingency allowance for variations.

10.2 Research Aim and Objectives

This research was an exploratory and analytical investigation of variations on construction projects. Defined as changes or modifications of the project after the letting of contracts, variations are one of the major causes of disruptions, disputes and claims on construction projects with impact on the project cost and time performance.

It was with this realisation that the research sort to contribute to existing knowledge of the problem. With this in mind, the research aims and objectives were developed as outlined in chapter one. Through these aims and objectives, the research evaluated the current approach to the planning and management of variations, resulting in an improvement in current practices.

10.3 Research Methodology

A four phased methodology was developed (chapter five) in line with the nature and scope of the research. These phases included the following;

(i) comprehensive literature review,

(ii) pilot study and analysis,

(iii) main research study, and

(iv) model development and validation.

10.4 Conclusions

The whole structure of the construction industry and the organisation of its production process is decisively affected by the fact that its products are sold before they are produced, and hence the production environment is fraught with risk and uncertainty. This is substantially different to other manufacturing industries.

Consequently, the usual methods of product appraisal prior to purchase are not possible. Therefore variations to the project, after the contract has been signed are unavoidable and part of the construction production process. The research results confirmed this proposition. All the projects studied generated variations, and a large number of those had a significant impact on the project's cost and time performance.

The research has addressed two propositions. The first being that there are a number of construction process factors that influence the magnitude of variations formed the starting point for the research investigation. This lead to a second proposition; that those factors can be used to predict the magnitude of variations. These propositions formed the basis of the primary and secondary research hypotheses, lay the basis for efficient planning and control of variations, since what is not properly planned cannot be effectively controlled.

The main conclusion to be drawn with regards to the factors influencing the magnitude of variations is that there are number of significant construction process factors influencing the magnitude of variations.

Client characteristics in terms of type and experience were examined. It was found that client type, as an indication of source of funding, is a significant influencing factor affecting the magnitude of variations on construction projects. Public clients are found to generate less variations. Tighter budget and public accountability induce a more conservative approach by public clients, one which is sufficiently flexible to control the budget. In contrast, private clients are found to place more emphasis on quality and timely completion.

The clients' past experience of the construction process, as measured by the number of previous projects was also found to be a significant factor. Experienced clients are found to generate less variations compared to inexperienced clients. Proper consideration of the decisions to make changes, and evaluation of subsequent effects of those changes, were based on knowledge and experience of construction.

The magnitude of variations was also found to be influenced by project characteristics, namely; type, size, complexity and duration. Office or industrial projects types with high cost and complexity, and longer duration, generate more variations than relatively moderate projects such as residential or educational buildings.

Design duration, and design completion were also found to influence the magnitude of variations. If adequate time is allowed for the designer to develop optimum design solutions, the magnitude of variations, due to design error or changes will be reduced significantly. Other important organisational factors were; construction duration; adequacy and availability of information; number of subcontracts; and environmental factors.

Based on the relationships between variations and these construction process factors, a quantitative model was developed as described in chapter eight. This predictive model, based on artificial neural networks technique, was tested and validated.

The test validity results of the model support the second research proposition. Contrary to the traditional practice, this research has proved that the variations' contingency can be objectively and realistically predicted within an acceptable level of accuracy. Accurate forecasts of the contingency are found to be critical to successful planning and control of variations and, subsequently, achieving improved project performance. Based on the traditional approach, over ninety percent of forecasted contingencies are found to be significantly lower than the actual total cost of variations. This indicates that the industry needs to take advantage of the cumulative research development, such as shown in this research, to improve planning and control of variations.

10.5 Recommendations

The construction process is governed by complicated contracts and involves complex organisational relationships. This complexity, and the unique nature of construction projects, makes variations difficult to manage properly. Effective management of variations can only be achieved through :-

(i) a good knowledge of the sources and nature of variations, and

(ii) an understanding of the complex relationships of factors influencing the magnitude of variations.

Of the numerous and diverse decisions involved in managing variations on construction projects, forecasting the contingency for variations is probably the most neglected part of project planning. From the review and results of the research investigation, professionals responsible for preparing the project budget or estimate, use a traditional approach to established the variations' contingency. Although, they consider this contingency to be dependent on various construction process factors, those factors are not assessed in any formal or structural manner. As discussed in the thesis, this traditional approach has a number of weaknesses. The contingency amount is arbitrarily determined, and often inappropriate for the specific project. Also, the contingency amounts are often overly simplistic to be realistic.

The research has shown the traditional approach to be inadequate and illogical in its determination of variations' contingency. The quantitative tool developed in this research has shown that, not only can the contingency be predicted with better accuracy, but (with available computer technology) a formal and structured methodological approach is feasible. With this approach, a logical and justifiable contingency can be consistently established. Once a properly established contingency is determined, project management can effectively control variations when they occur, since they have been properly planned.

Problems encountered are often to do with whether the works involved constitute a variation. This often leads to the failure of a reasonable negotiation and often results in disputes, claims and lengthy litigation. These problems could be easily be resolved if the contingency is adequate in the first place. When the established contingency has run out, the project manager will often dispute the contractors' cost estimates of the varied work in order to cover his own negligence (i.e.in forecasting an adequate contingency in the first place). The common excuse is not to accept the work as a variation.

Therefore, the main recommendations of this research is that the contingency should be properly determined at the project planning/budgeting stage for the control of variations during the course of the project to be effective. This should, subsequently, reduce project disruption, disputes, and claims, and thereby improve performance.

10.6 Further Research

The nature of the research investigation reported is said to be exploratory and analytical compared with previous similar research. However, the research has help towards the main objectives of the investigation as reported in the thesis. Further research work which could be conducted in light of the results reported can be identified as follows:

(i) the quantitative model developed needs developing and rigorous further testing on a larger number of case study data;

(ii) the model needs to be developed into a user-friendly software (with proper user interface);

(iii) develop a methodology for quantitative evaluation of the cost benefits and potential improvement for implementing the model in practice;

(iv) research into how the predicted contingency can be distributed to work sections of the project;

(v) further analysis of the research findings and comparison with civil and heavy engineering sectors.

The generalisation drawn from this research can serve as propositions or hypotheses to be tested by future research based on the issues listed above.

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APPENDIX A

RESEARCH QUESTIONNAIRE

The University of Wolverhampton
School of Construction Engineering & Technology

RESEARCH QUESTIONNAIRE

"Variation" refers to changes or modifications of the project by addition, omission, substitution or alteration, after the contract has been awarded.

The questionnaire consists of 2 parts:

Part 1: Invites brief information about your organisation for data classification purposes.

Part 2: This part consists of three sections A, B & C. All the questions in these three sections relate to a single construction project completed by your organisation in the last 5 years.

section A: Invites brief information about the project you choose and the incident and type of variations on the project.

section B: Analyses in more detail the factors which might influence the number and value of variations on construction projects.

section C: Invites you to evaluate the variation clause(s) contained in the condition of contract used for the project.

Name ....

Position in company ....

Name of company ....

Date ....

PART 1
GENERAL INFORMATION ABOUT YOUR ORGANISATION

1. Which of the following best describe your organisation?

[ ] Contractor
[ ] Architect
[ ] Engineering
[ ] Quantity Surveyor
[ ] Developer
[ ] Others, please specify

----

2. Which of the following best describe the nature of your organisations' activity?

[ ] building
[ ] building and civil engineering
[ ] architectural design and management consultant
[ ] civil/mechanical/electrical engineering
[ ] speculative developer
[ ] others (please specify)

----

3. What is the approximate turnover of your organisation per annual?

[ ] less than £5M
[ ] £5M - £10M
[ ] £10M - £25M
[ ] £25M - £50M
[ ] £50M - £100M
[ ] over £100M

PART 2:
SECTION A: PROJECT DESCRIPTION

Responses to this section should be in reference to a single construction project. Choose a project completed within the past 5 years typical of your organisation's activity.

Project name/code....................................

Project client.......................................

Project Location....................................

Please give the following detail (if related)

Gross floor area ....

No. of storey(inc. basement).....................

1. Which of the following best described the client/owner's organisation?

local government [ ]
central government [ ]
nationalised industry [ ]
developer [ ]
private company [ ]
private individual [ ]
others (specify) [ ].........................

2. Which of the following best described the project type?

a. Office [ ] d. Education [ ]
b. Industrial [ ] e. Residential [ ]
c. Health [ ] f. Other(please specify) [ ]

----

3. Please indicate form of construction:
a. steel frame [ ] c. brick [ ]
b. reinforced concrete [ ] d. steel & R. concrete[ ]
e. others (specify) [ ]

----

4. How would you described the type of contract and the project procurement method? (Please tick one box)

	Traditional	Management contracting	Design & Build	Construction management	Other ------------
Lump sum					
Cost plus fee					
Cost plus % fee					
Fixed cost					
Target price					
Other -----------					

5. How would you rate the following design characteristics:
   a. design completion? Low [ ] Average [ ] Full [ ]
   b. designer experience Low [ ] Average [ ] Full [ ]

6. What method of contractor selection was used for the project ?

   a. Open tender [ ] b. Selective tender [ ]
   c. Direct nomination [ ] d. Other(specify) [ ]

   ....

7. Which of the following documents form part of the tender documents?

   a. bill of quantity [ ]
   b. approximate bill of quantity [ ]
   c. schedule of rates [ ]
   d. other(please specify) [ ]

   ....

8. Please specify the standard form of contract used for the project:

....

9. Project costs:

a. project tender/estimated cost £.............

b. project actual cost £.............

10. Project duration (month):

	planned	actual
a. Design phase	....	....
b. construction phase	....	....
c. Total project duration	....	....

11. How would rate the following production factors?

a. contractors' experience Low [ ] Average [ ] high [ ]

b. adequacy of information Low [ ] Average [ ] high [ ]

12. Number of sub-contract: ____________________

13 Please rate the effect of the following Environmental Factors:

	Low	Average	High
4.1 Economic influence	[ ]	[ ]	[ ]
4.2 Social influence	[ ]	[ ]	[ ]
4.3 Political influence	[ ]	[ ]	[ ]
4.4 Technological influence	[ ]	[ ]	[ ]

14. Please give the approximate number of variations on the project?

----

15. Total value of variations £.............

Please rank the following questions using a 10 point scale where 0= very low,.... 10=very high.

16. Please rate the following as a major source of the variations on the project:

[ ] design choice
[ ] client choice
[ ] client change of mind
[ ] contractor
[ ] defect in design
[ ] inadequate information
[ ] incorrect assessment of brief
[ ] defect in documentation
[ ] unforeseen events
[ ] others(please specify)----------------------

17. Rate the frequency of the following nature of variations on the project:

[ ] addition
[ ] omission
[ ] alteration
[ ] substitution
[ ] change of materials
[ ] other (please specify)

SECTION C: VARIATION CLAUSE(S) EVALUATION

Please indicate your agreement to the following attributes of the variation(or change) clause(s) contain in the condition of contracts used for the project on a 10 point scale, where 0=strongly disagreed,.... 10=strongly agreed.

1. **Definition:** the contract clearly defined what was a variation. [ ]

2. **Completeness:** the clause(s) is comprehensive and covered all relevant aspects of variation procedure. [ ]

3. **Practicality:** the time requirements in the clause for variation instruction, confirmation and negotiation of cost before the work is done, is practicable. [ ]

4. **Valuation:** the procedure outline for measurement and valuation of variations are clearly defined and adequate. [ ]

5. **Consistency:** variation clause(s) and sub-clauses are consistence. [ ]

6. **Fairness:** variation clause(s) is fair and just. [ ]

7. **Cost:** variation clause(s) is used to control the project cost. [ ]

8. **Time:** variation clause(s) is used to control project duration. [ ]

9. **Performance:** the clause(s) promote completion of the project in time and within budget. [ ]

Would your company be willing to provide further information regarding this project?

a. Yes [ ]
b. No [ ]

Please make any comment or suggestion on the back of this page.

Thank you for your time.

Please forward complete questionnaire to:

A. O. Akinsola
"Variations on Construction Projects" Research
School of Construction Engineering & Technology
University of Wolverhampton
Wulfruna Street
Wolverhampton WV1 1SB.

APPENDIX B

VALIDATION CASE STUDY QUESTIONNAIRE

VARIATIONS ON CONSTRUCTION PROJECTS

CASE STUDY DATA-FORM

Please select a project completed by your organisation within the last 5 years as the case study project and complete this data-form.

Project Description:

Project name/code:____

____

Project location: ____

****

1. Client Characteristics:

1.1 Client sector: public/private

1.2 Type of client:
- a. local government [ ]
- b. central government [ ]
- c. developer [ ]
- d. private company [ ]
- e. other ____________________ [ ]

1.3 Business activity:
- a. public services [ ]
- b. speculative/commercial developer [ ]
- c. manufacturing [ ]
- d. others____________________ [ ]

1.4 Experience of construction: a. very experienced [ ]

b. experienced [ ]

c. inexperience [ ]

2. Project Characteristics:

2.1Type: a. office [ ] b. road [ ]

c. industrial [ ] d. highway [ ]

e. education [ ] f. bridge [ ]

g. health [ ] h. drainage/sewer [ ]

i. residential [ ] j. dam [ ]

k.others (specify please) [ ] ______________________________

2.2 Project cost: budget/estimated cost:£__________________________

actual project cost: £__________________________

contingency allowance £__________________________

2.3 Project durations:

	planned (months)	actual (months)
design phase	____________	________________
construction	____________	________________
total duration	____________	________________

3. Organisation Factors:

3.1 Procurement method:

a.traditional [ ] b. design build [ ]

c.management contract [ ] d. others__________[ ]

3.2 Type of contract:

a. lump sum [ ] b. cost + % fee [ ]

c. cost + fee [ ] d. fixed cost [ ]

e. target cost [ ] f. others______________ [ ]

3.3 Method of tender:

a. open [ ] b. selective [ ]

c. direct [ ] d. others__________[ ]

3.4 Tender documentation:

a. bill of quantity [ ] b. approx. bill of quantity [ ]

c. schedule of rates [ ] d. others _____________ [ ]

3.5 Tender duration: _________________________(weeks)

3.6 Adequacy of information:

a. very [ ]

b. average [ ]

c. low [ ]

3.7 Number of sub-contract: ___________________

4 Environmental Factors:

	Low	Average	High
4.1 Economic influence	[ ]	[ ]	[ ]

4.2 Social influence	[ ]	[ ]	[ ]
4.3 Political influence	[ ]	[ ]	[ ]
4.4 Technological influence	[ ]	[ ]	[ ]

5. Variations:

5.1 Total number of variations ____________________

5.2 Total cost of variations £____________________

INFLUENCING FACTORS

Please indicate the level of influence of the following factors on the number and value of variations on the project on a scale 0 - 10, where 0=no influence,..... 10= very influential.

01. **Client Characteristics:**
1.1 client type [ ]
1.2 client experience [ ]

2. **Project Characteristics:**
2.1 project type [ ]
2.2 project size: [ ]
2.3 project complexity [ ]

3. Tender
3.1 tender document [ ]

4. Production
4.1 number of subcontractor [ ]
4.2 Adequacy of information [ ]

5. **Environmental Factors:**
4.1 economy [ ]
4.3 political [ ]
4.5 technology [ ]

Thank you for your time

Appendix C
Correlation Analysis Matrix

	cc1	*cc2*	*cc3*	*pc1*	*pc2*	*pc3*	*pc4*	*dc1*
cc1	1.000							
cc2	0.237	1.000						
cc3	0.142	0.367	1.000					
pc1	-0.431	-0.466	-0.057	1.000				
pc2	0.486	0.272	0.386	-0.275	1.000			
pc3	0.619	0.236	0.266	-0.304	0.774	1.000		
pc4	0.024	0.161	0.248	-0.174	0.378	-0.005	1.000	
dc1	0.062	0.151	0.185	-0.217	0.459	0.088	0.827	1.000
dc2	0.297	0.440	0.219	-0.270	0.178	0.167	-0.010	0.019
dc3	0.170	0.099	0.024	-0.132	0.203	0.229	0.101	0.096
tp1	0.239	0.160	0.102	-0.214	0.153	0.126	0.367	0.220
tp2	0.272	0.245	0.033	-0.214	0.120	0.144	0.071	-0.059
pf3	0.292	0.200	0.323	-0.285	0.321	0.360	0.132	-0.020
pm1	0.231	0.077	-0.059	0.009	0.028	0.222	-0.132	-0.222
pm2	-0.081	-0.054	-0.167	0.192	-0.186	-0.166	-0.183	-0.337
pf1	0.113	0.038	0.126	0.076	0.412	0.053	0.606	0.574
pf2	0.123	0.306	0.167	-0.183	0.068	0.025	0.186	0.062
pf4	0.389	0.248	0.128	-0.002	0.367	0.419	-0.167	-0.106
ef1	0.072	0.092	-0.001	0.141	-0.114	-0.057	0.017	-0.183
ef2	-0.078	0.156	0.052	-0.002	-0.067	-0.145	-0.008	0.088
ef3	-0.129	0.141	-0.123	0.143	-0.237	-0.211	-0.206	-0.154
ef4	-0.021	0.299	0.366	-0.103	0.178	0.080	-0.040	-0.016
TCV	0.500	-0.339	0.131	-0.369	0.762	0.778	0.312	-0.038
TNV	0.260	-0.406	0.321	-0.179	0.676	0.557	0.232	-0.089

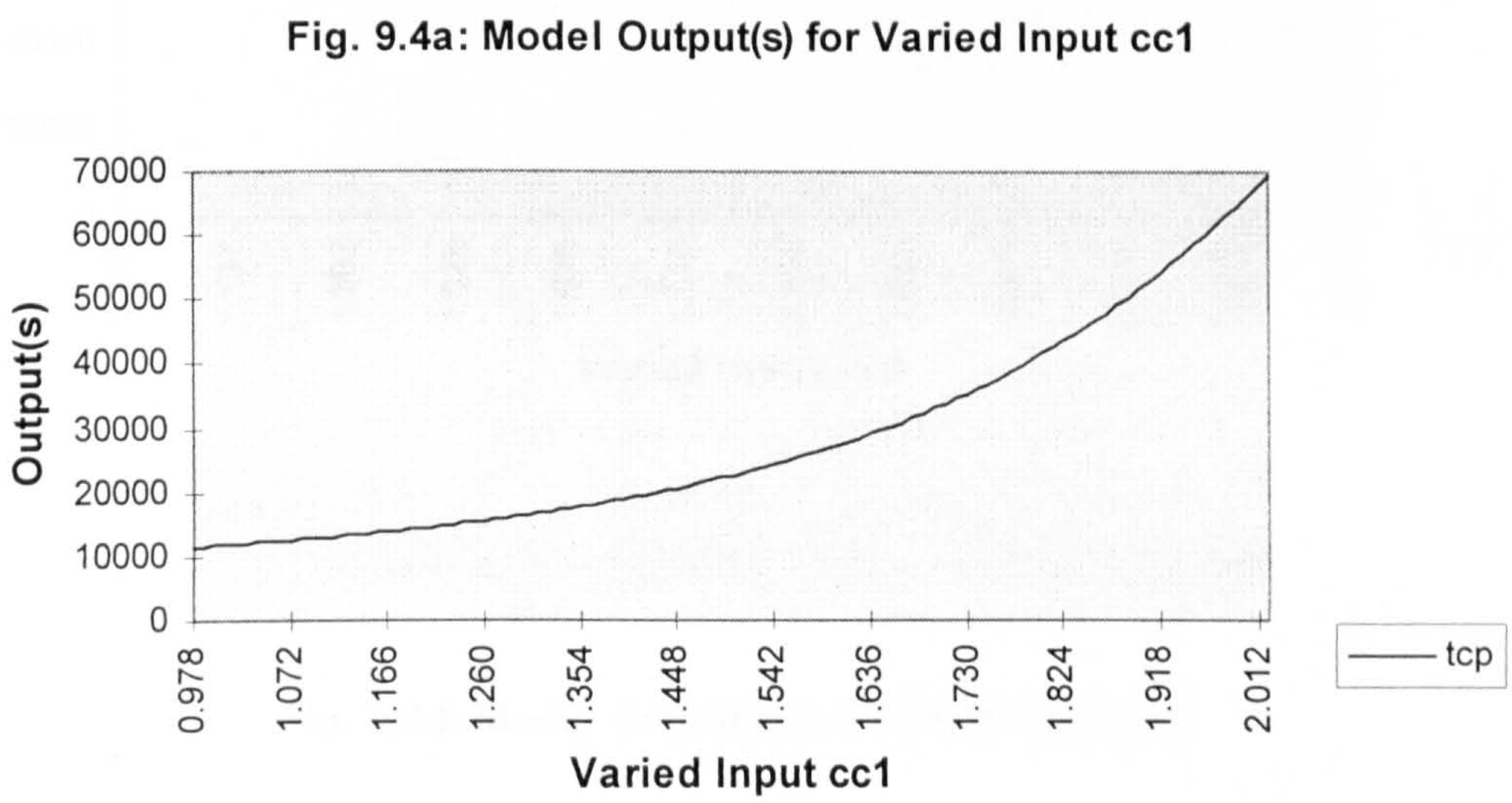
dc2	*dc3*	*tp1*	*tp2*	*pf3*	*pm1*	*pm2*	*pf1*	*pf2*
1.000								
0.208	1.000							
0.069	0.220	1.000						
0.068	0.284	0.420	1.000					
0.206	0.561	0.173	0.197	1.000				
0.145	0.218	0.199	0.517	0.103	1.000			
-0.054	0.011	-0.123	-0.029	0.006	0.052	1.000		
-0.028	0.127	-0.018	-0.045	0.017	-0.134	-0.071	1.000	
0.605	0.358	0.196	0.075	0.229	0.179	-0.072	0.006	1.000
0.319	0.186	0.090	0.044	-0.058	0.206	0.075	0.155	0.234
0.132	0.209	0.023	0.077	0.148	0.014	0.355	0.077	0.391
0.206	-0.032	-0.274	-0.230	-0.051	-0.149	0.057	0.071	0.155
0.055	-0.027	-0.266	0.126	-0.273	-0.036	0.358	-0.055	-0.012
0.341	-0.097	-0.208	-0.103	0.144	-0.211	0.171	-0.103	0.112
-0.462	-0.265	0.076	0.011	-0.369	0.005	-0.208	0.331	-0.035
-0.363	-0.237	0.061	-0.018	-0.304	0.183	-0.127	0.224	-0.135

pf4	ef1	ef2	ef3	ef4	TCV
1.000					
0.160	1.000				
0.165	0.077	1.000			
0.145	0.231	0.391	1.000		
-0.098	0.051	0.104	0.355	1.000	
0.174	-0.116	0.057	-0.252	0.077	1.000
0.261	-0.004	0.037	-0.105	0.249	0.223

Appendix D
Sensitivity Analysis

Results of Sensitivity Analysis

This Appendix shows the graphs of the sensitivity of the ANN model to changes in the input factors.



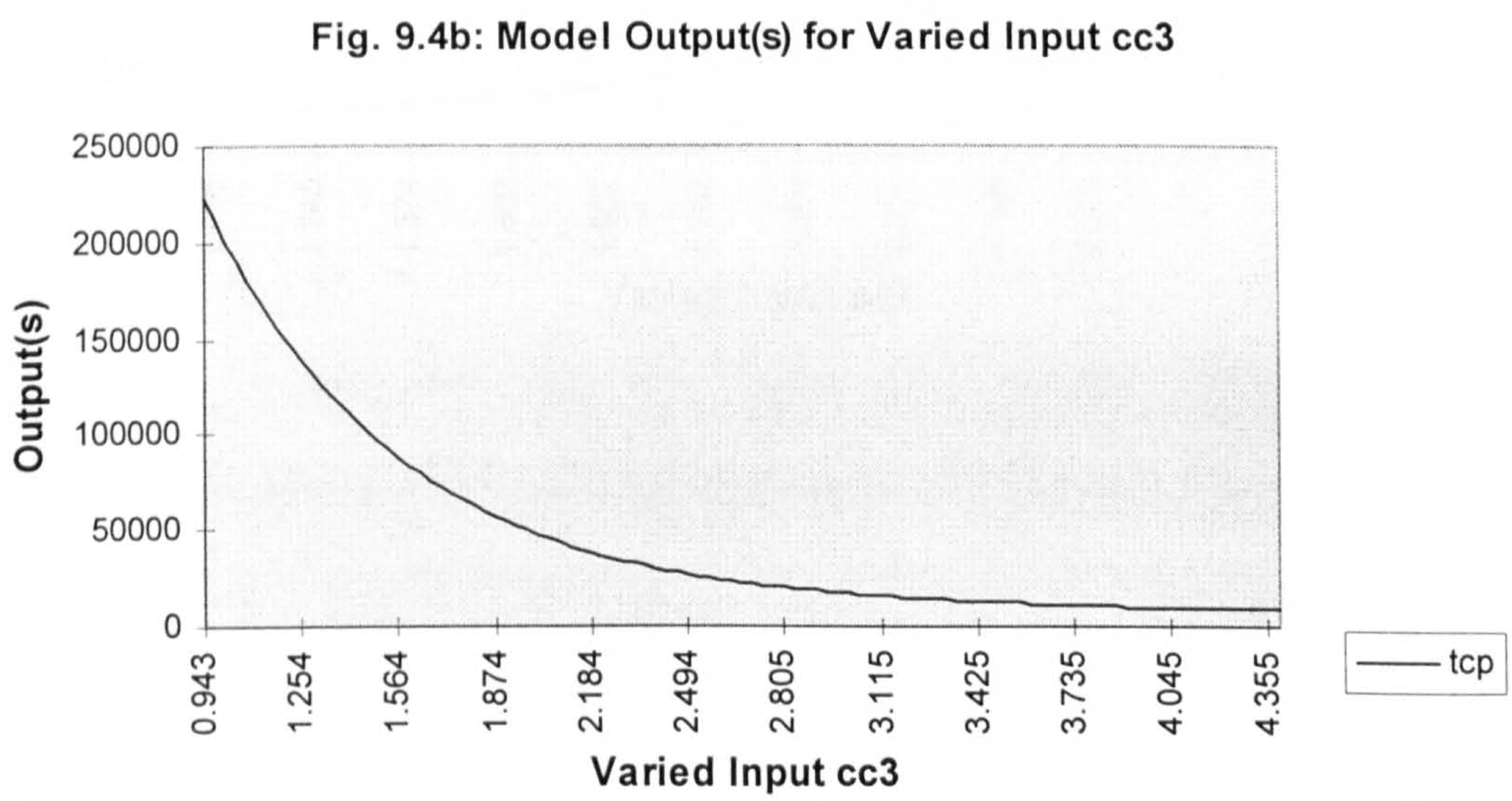


Fig. 9.4c: Model Output(s) for Varied Input pc2

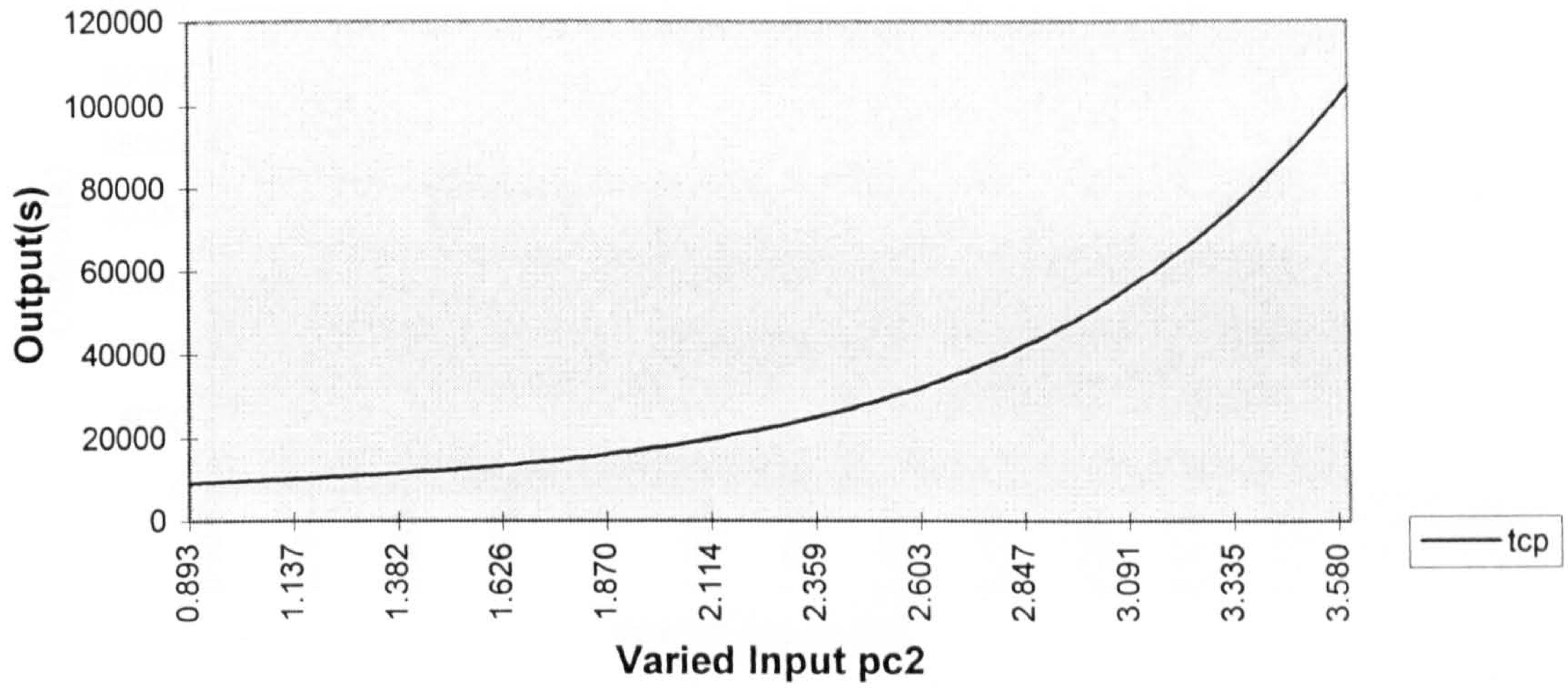


Fig. 9.4d: Model Output(s) for Varied Input pc3

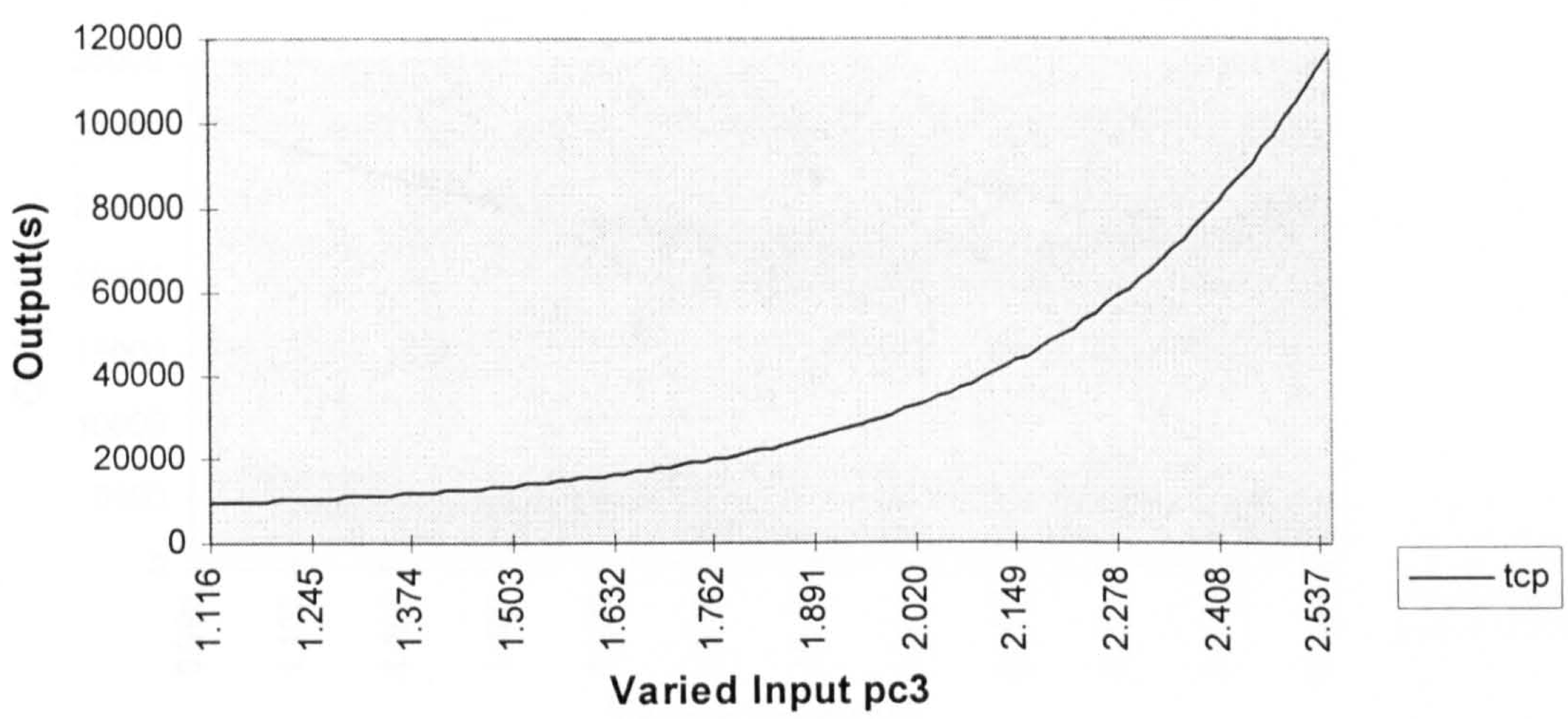


Fig. 9.4e: Model Output(s) for Varied Input tp2

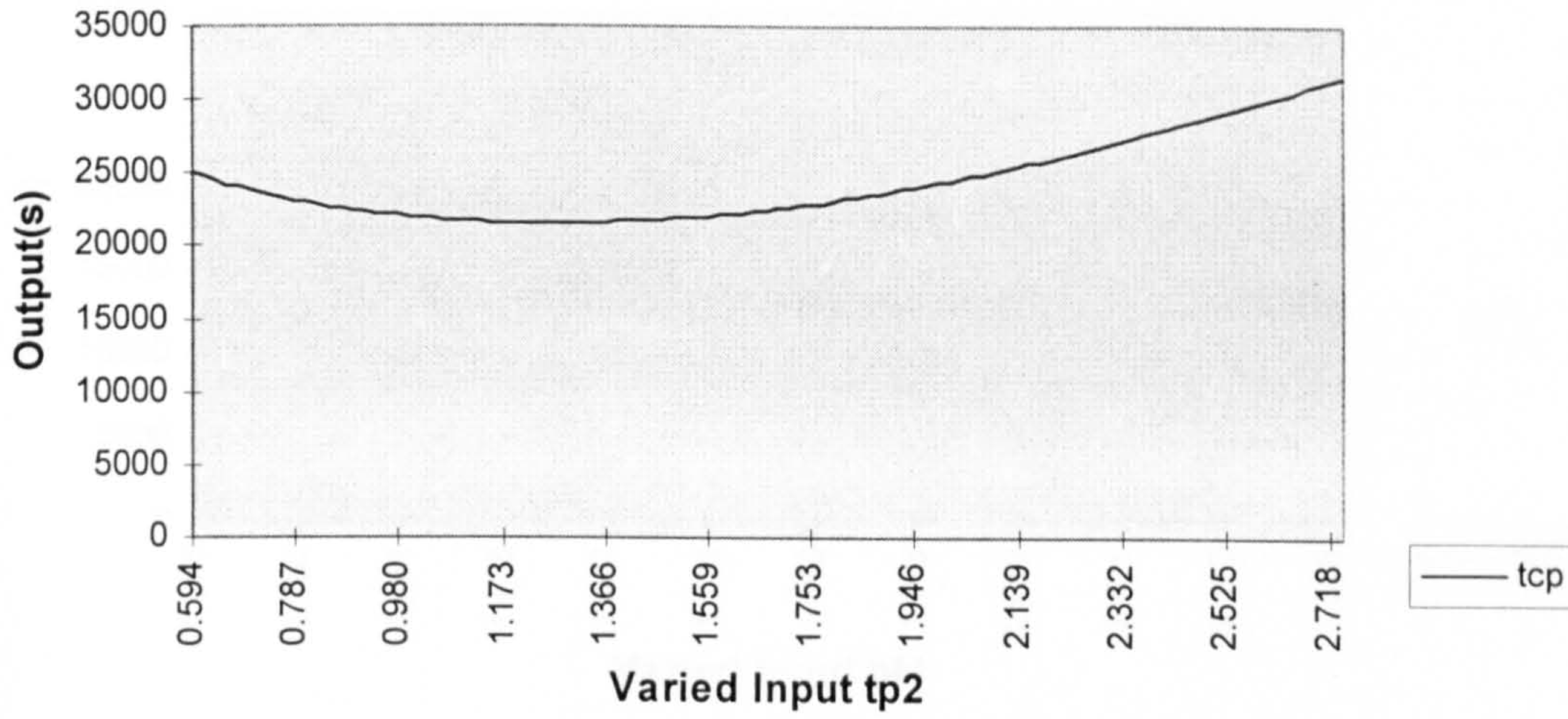


Fig. 9.4f: Model Output(s) for Varied Input pf3

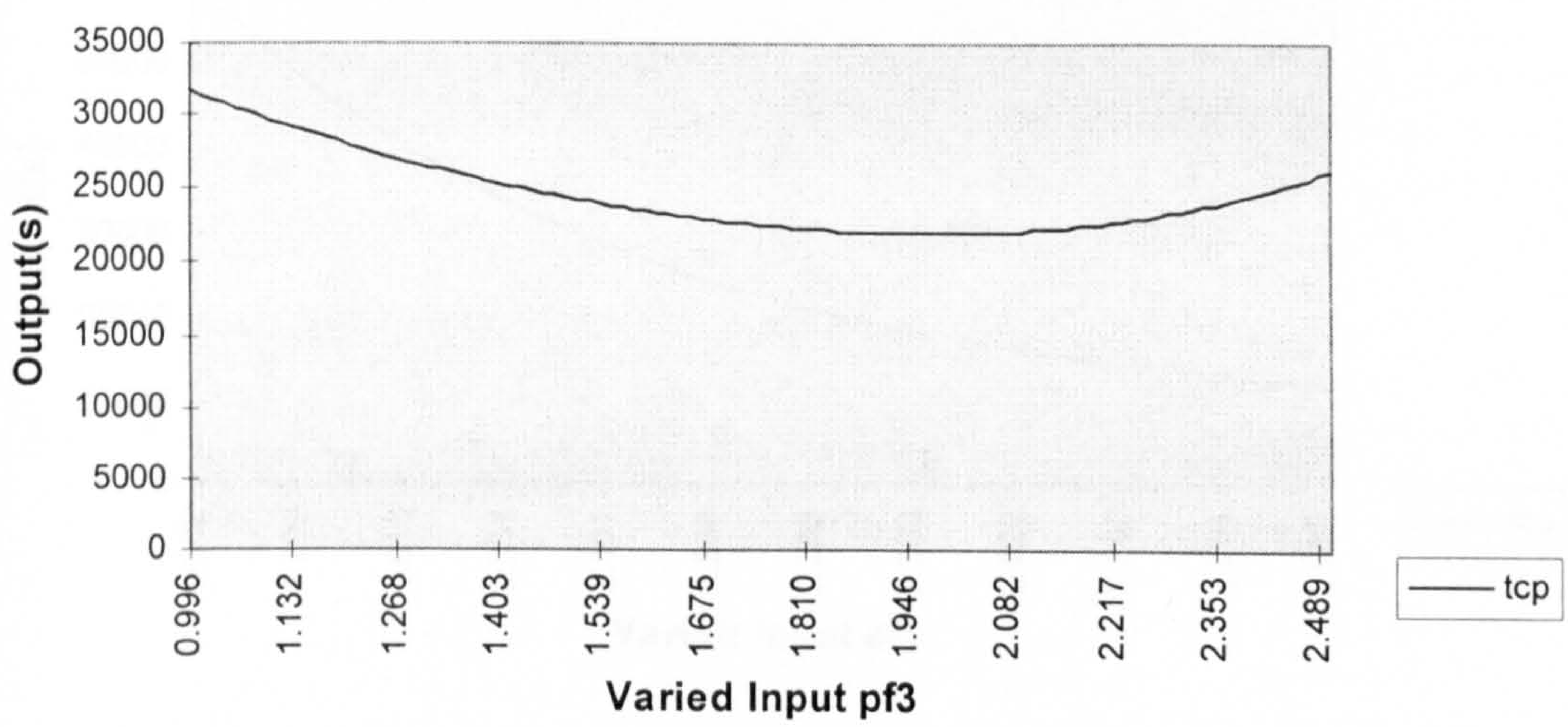


Fig. 9.4g: Model Output(s) for Varied Input pf4

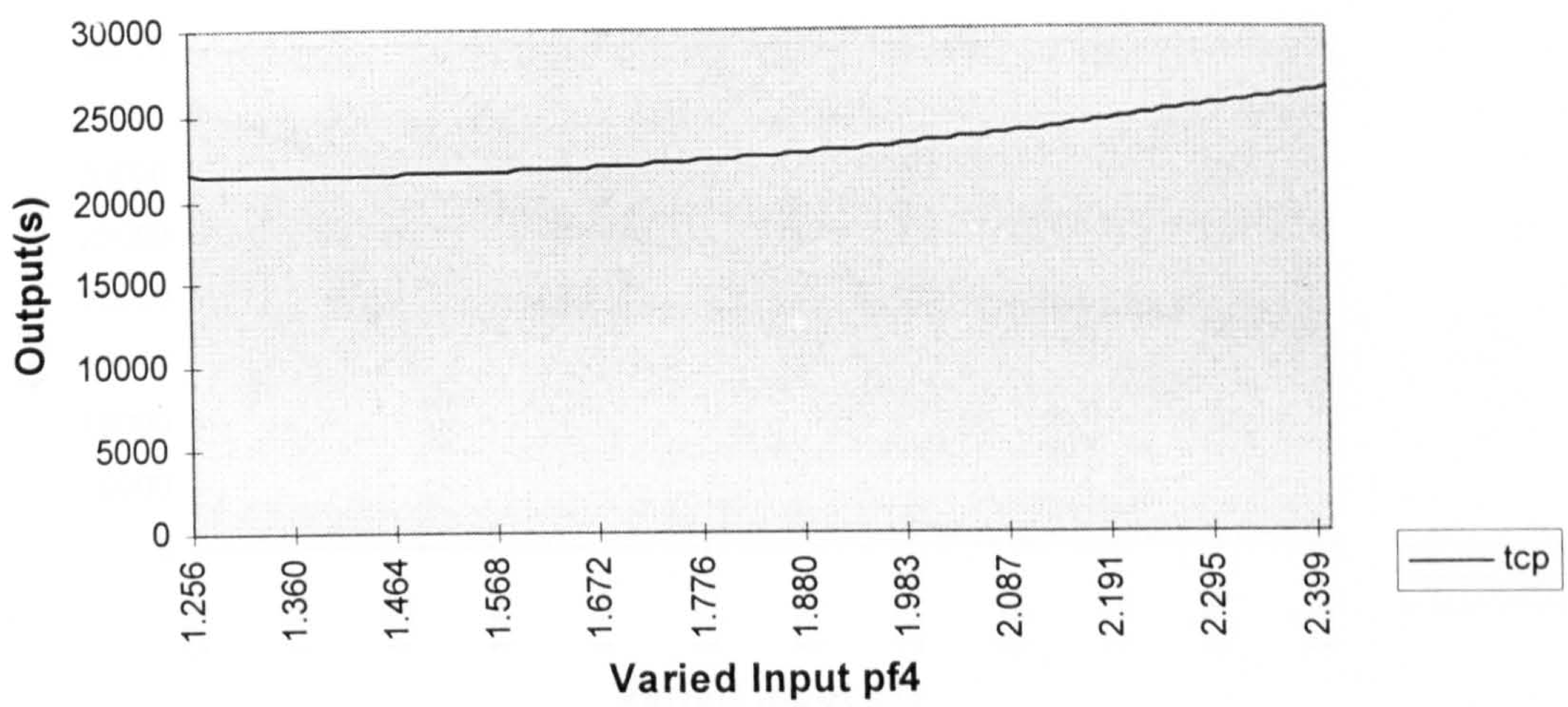


Fig. 9.4h: Model Output(s) for Varied Input ef1

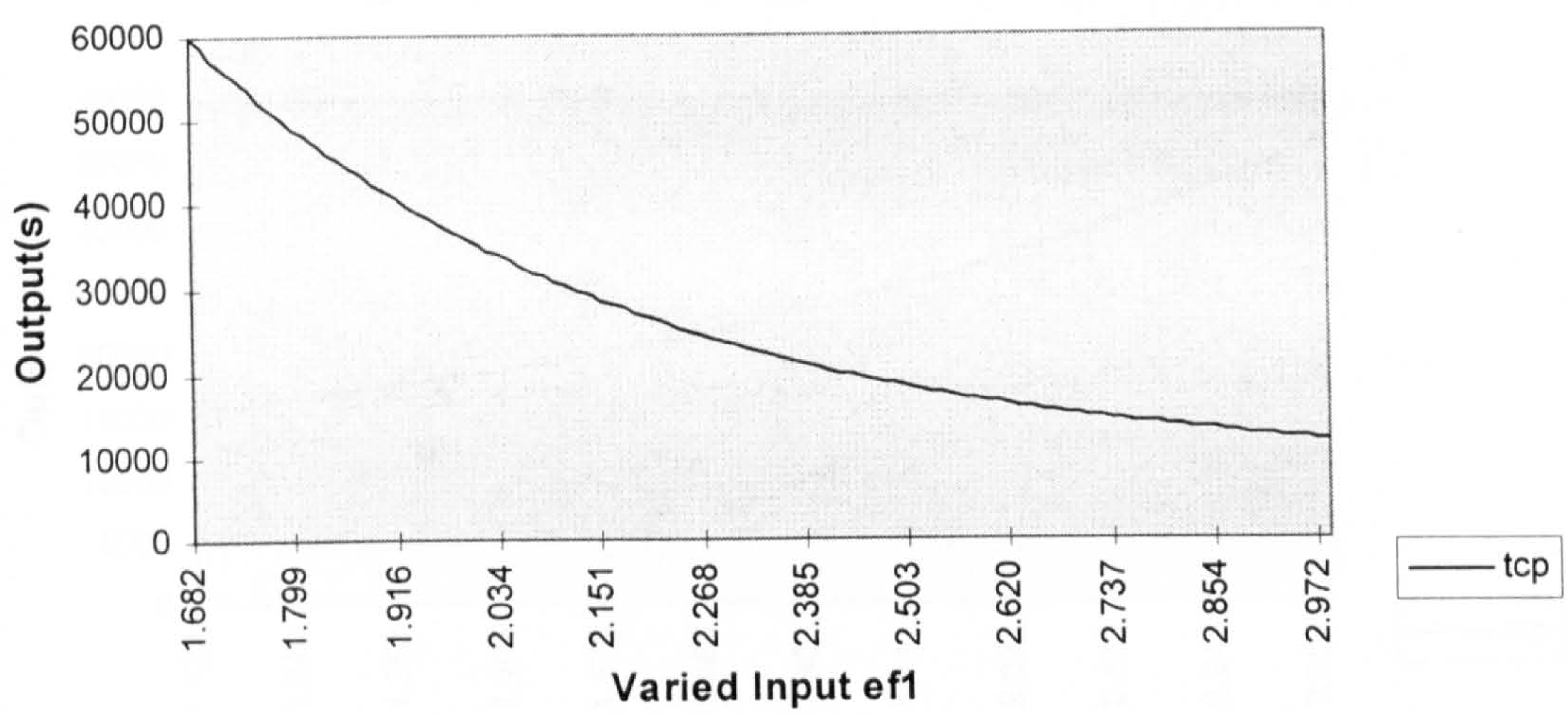


Fig. 9.4i: Model Output(s) for Varied Input ef3

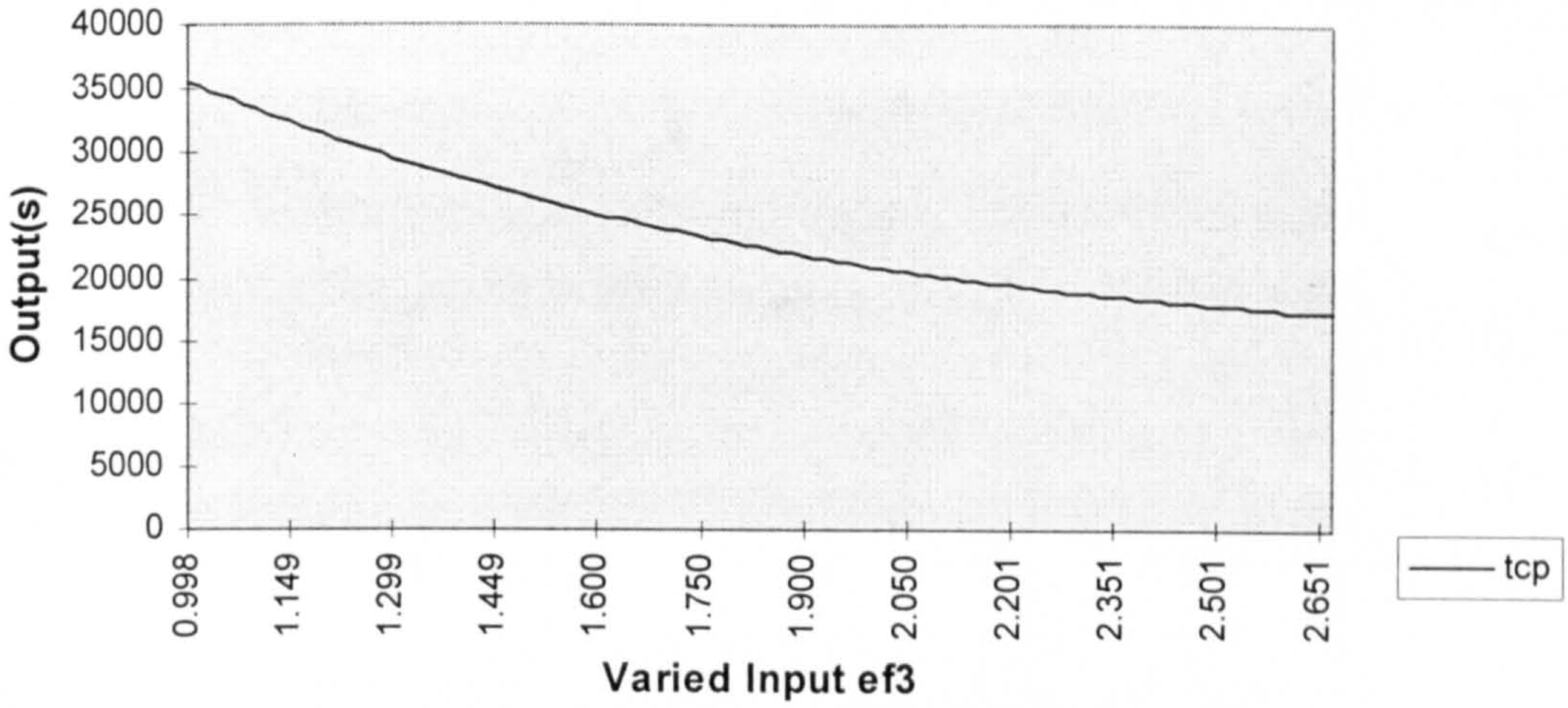
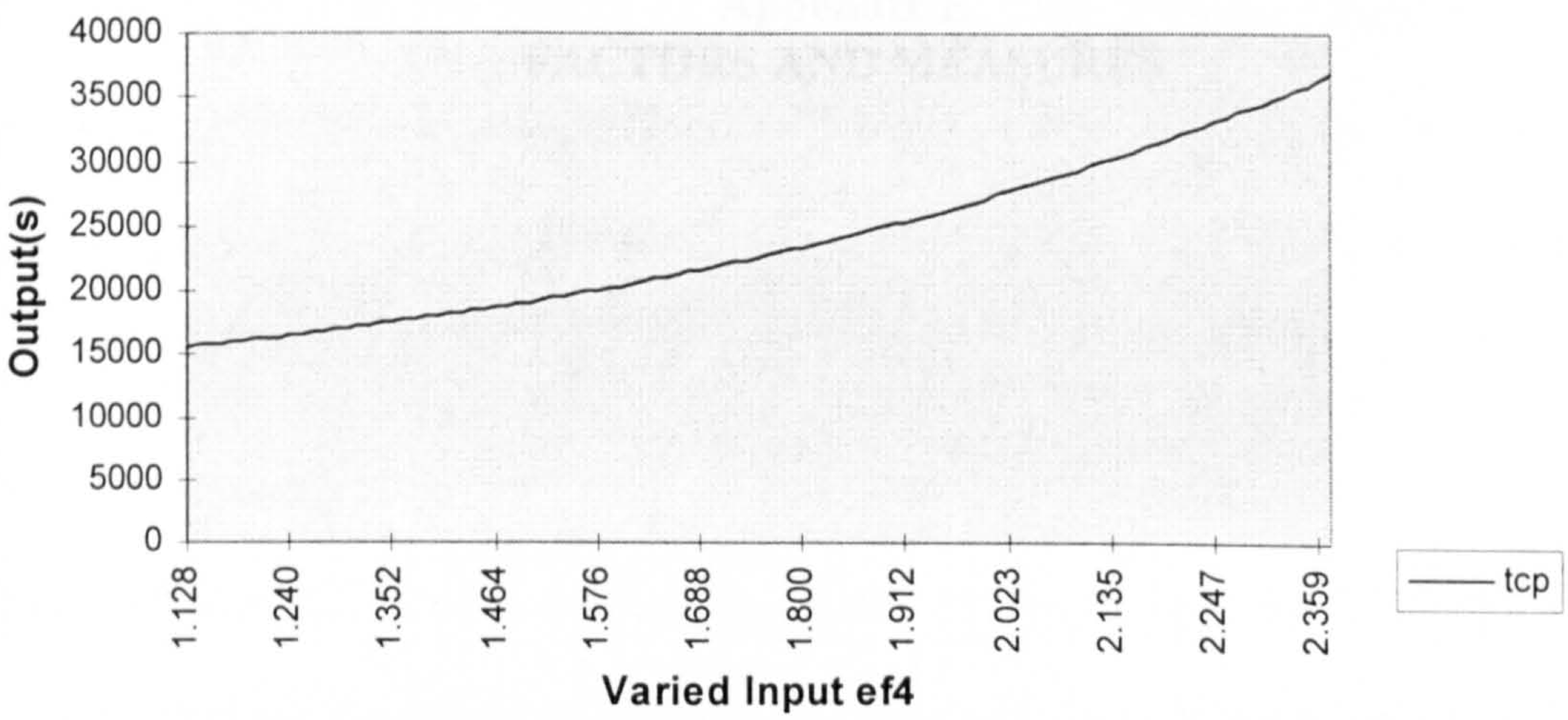


Fig. 9.4j: Model Output(s) for Varied Input ef4



Appendix E
FACTORS AND MEASURES

FACTORS AND MEASURES

Factors identified and investigated in this study can be grouped into four categories: client characteristics, project characteristics, organisation strategy, and environmental factors.

Client Characteristics

Client type (CC1), defined as the source of project funding, were categorised as either public (1), or private (2).

Client experience (CC2), defined clients' level of experience and knowledge of construction industry and its production process. Clients who had considerable experience (i.e. been involved with more than two construction projects in the past) were given a score of High (or ranked 1). Those with some previous experience (i.e. been involved with one or two project before) were give a score of Average (or rank 2). And those with no experience or knowledge of construction were given a Low score (or ranked 3).

Client business (CC3), was defined as clients' nature of business or purpose for the building and was categorised as either public services (1), speculation/commercial (2), or private/manufacturing (or any other purposes) (3).

Project Characteristics

Project type (PC1) defined the use of the building after completion. Buildings were categorised as either office (1), industrial (2), health (3), education (4), residential (5), or others than the above (6).

Project size (PC2), was defined the total cost of the project. In order to make a fair comparison, the classified into six groups; less than £1m, £1-5m, £5-15m, £15-25m, £25-50m, and over £50m. The boundary ranges were decided after considering the frequency and normal distribution of the data included in each group.

Project complexity (PC3), was defined in terms of the construction rate. The construction rate, which is the cost of the project divided by the construction duration (cost/month), was used as indication of the technical complexity of the project.

Project duration (PC4), defined, in months, the total duration of the project from inception to completion.

Organisation Strategy

Designers' experience (DC1), was measured in the same way as for the clients' experience above.

Design duration (DC2), defined, in months, the duration of the project design, from client's brief to completion of the detail design.

Percentage of design completed (DC3), defined as proportion of the design completed before the contract was put to tender. Projects where the design were fully completed before tendering were given a score of 'fully' completed (or ranked 1). Those with average completed design were given a score of 'average (or ranked 2), and those with outline or less detailed design were given a 'low' score (or rank 3).

Procurement method (PM1) were of three types, traditional method (given scored of 1), management contracting (given score of 2), or design build (with score of 3).

Type of contract (PM2) were classified into five types; lump sum (1), cost plus fee (2), cost plus percentage fee (3), fixed cost (4) and other types (5).

Method of tendering (TP1) was defined as the method used to select the contractor and was categorised as either open tendering (1), selective tendering (2), direct nomination (3), or any other method (4).

Tender documentation (TP2), defined type of tender documentation used for pricing and categorised as either bill of quantity (1), approximate bill of quantity (2), schedule of rate (3), or any other document (4).

Contractors' experience (PF1) was measured by the number of similar or type of projects built in the past and scored in the same way as for the experience of clients above.

Construction duration (PF2) measured the construction duration from site clearance to completion and hand-over, in months.

Adequacy of information (PF3) evaluated the perception of the respondent on the sufficiency of information and time needed to acquire the information on a 10-point scale. A score of 4 or less is Low (or ranked 3), 4-7 is Average (ranked 2), and 7-10 is High (ranked 1).

Number of subcontractors (PF4) was measured by the number of subcontract and classified as less than 20 (ranked 3), 20-40 (ranked 2) and over 40 (ranked 1). The boundary ranges were decided after considering the frequency distribution of the data included in each of the three procurement methods group.

Environmental Factors

The four environmental factors- *economy, social, political* and *technology*, measured, on a 10-point scale, the perception of the respondent on the influence of those factors on decisions or causes of variations incidents on the project. A score of 4 or less is ranked as Low, 4-7 as Average, and 7-10 ranked as High.

Appendix F

Validation Case Study Projects Description

Case Study Projects

Project A:

The project was a new clubhouse commissioned by a private organisation. As a leisure facility, the project was procured through a traditional route on lump sum contract. The project was completed within the estimated cost of £1.18m but overrun on time.

Project B:

Project B was a magistrate court commissioned by the central Government. Procured through a traditional method with lump sum contract, was initially estimated at £8.5m including £0.5m contingency. The project was completed on schedule with final cost of £12.5m.

Project C:

The project is a retail park for a private retail company an procured through a traditional method of procurement with lump sum contract. With an estimated budget of over £1m, the project was completed on time and below the budget.

Project D:

A new large commercial bank office building with an estimated cost of about £70m. The project was commissioned using a two stage procurement method with lump sum contract. The project was completed on time and within the budget.

Project E:

Project E was an office building for a private company client for own uses. The project with an estimated cost of just over £1m, was traditionally procured with lump sum contract. The project was completed late with an estimated cost overran of over 30%.

Project F:

Another office building with an initial cost estimate of over £2.5m. Traditionaaly procured with lump sum contract, the project was completed late with cost overran of about £0.5m.

Project G:

A residential building commissioned by a local authority in association with local housing association. The project was procured through a traditional procurement with a budget of £2.3m. Completed late, the project overran on both time and cost.

Project H:

Project H was new hall of resident for a University college with initial budget of £7.6m. The project, traditionally commissioned on a lump sum contract, was completed late with cost overran of over a million pounds.

Project I:

Project I was an education building commissioned by a local council. The project, procured traditionally, was initially estimated at £5.2m was completed late but below the budget.

Project J:

Was another education building for secondary school commissioned by local council. With an estimated cost of £4.2m and traditionally procured, the project was completed on time and within the budget.

Project K:

The project was a two storeyed residential building for a local authority. With traditional procurement method and estimated at £8.72m, the project was completed late but within the estimated budget.

Project L:

The was another residential building by an housing association traditionally commissioned. With a fixed cost contract, the project finished late with cost overran of £20k over the estimated project cost.